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August 1995

US Army Corps of Engineers
Waterways Experiment Station

Dredging Operations Technical Support Program

Dredging-Induced Near-Field Resuspended Sediment Concentrations and Source Strengths

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by *Michael A. Collins, Southern Methodist University*

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Prepared for Headquarters, U.S. Army Corps of Engineers

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by Michael A. Collins

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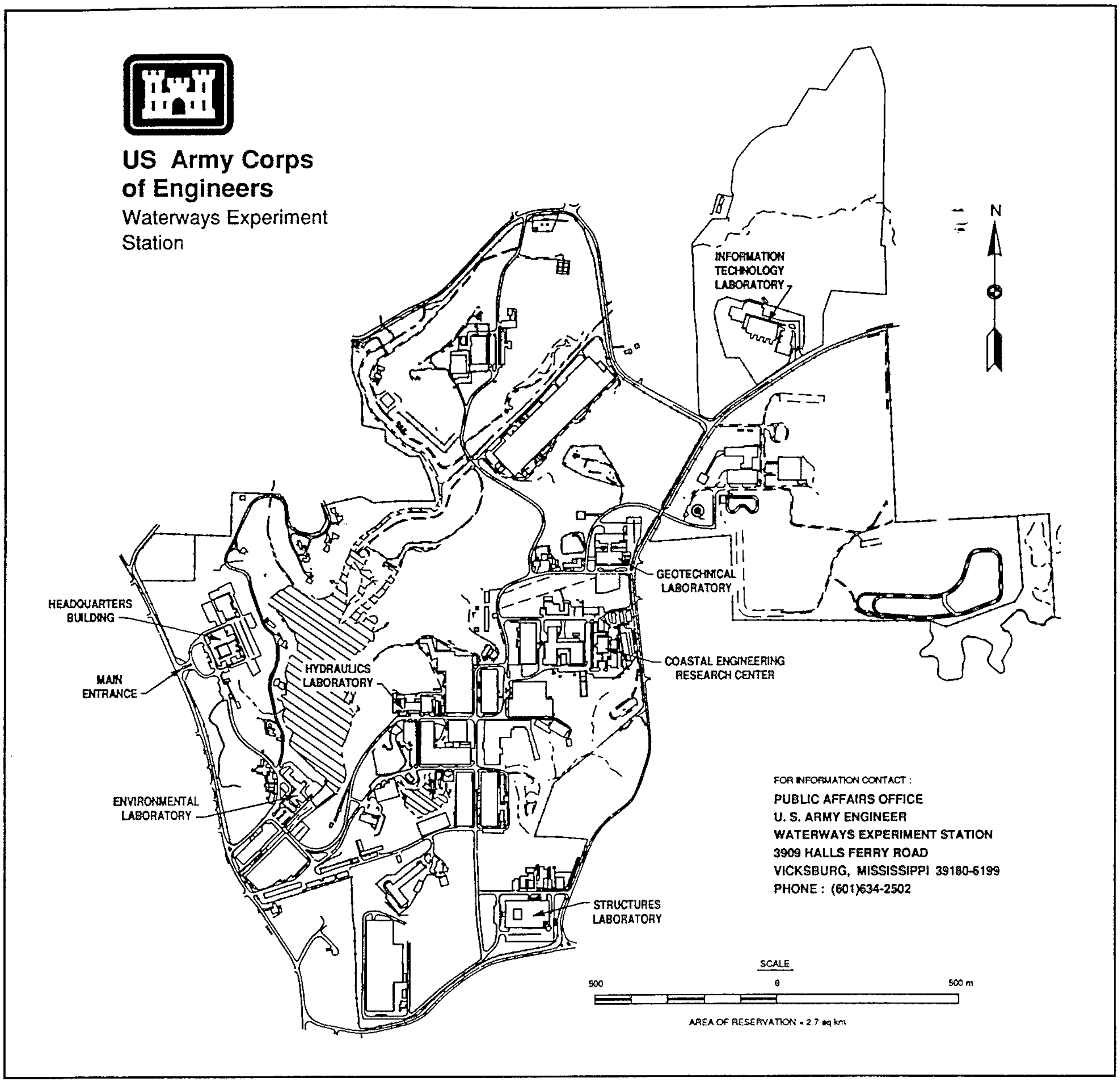

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Environmental Effects of Dredging Programs

Dredging Operations Technical Support

Report Summary

Dredging-Induced Near-Field Resuspended Sediment Concentrations and Source Strengths (MP D-95-2)

ISSUE: Dredging in riverine, lacustrine, and estuarine environments resuspends bottom sediments into the overlying water column. Dispersal of these resuspended sediments may pose water quality problems in waters near the dredging operations. Possible release of contaminants adsorbed on sediment particles, alteration of the physiocochemical properties of overlying or nearby waters, and the resettling of sediments in environmentally sensitive waters distant from the dredging operation are potential problems.

RESEARCH: This research entailed field studies to assess the suspended sediment concentrations in the water column in the vicinity of various dredge types. These concentration data were combined with conceptual models for resuspended sediment source strength geometries and velocity patterns to estimate sediment source strengths for cutterhead and clamshell dredges.

SUMMARY: The resuspended sediment source models developed in this study, although unverified, provide a starting point for a more thorough analytical evaluation of the entire resuspension, transport, and deposition process.

AVAILABILITY OF REPORT: The report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601) 634-2355.

To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4780. For help in identifying a title for sale, call (703) 487-4780. NTIS report numbers may also be requested from the WES librarians.

About the Authors: Mr. Michael A. Collins is a Consulting Engineer with Woodward-Clyde Consultants of Houston, TX. For further information about the Dredging Operations Technical Support Program, contact Mr. Thomas R. Patin, Program Manager, at (601) 634-3444.

August 1995

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Preface

The field studies discussed in this report were conducted by the Water Resources Engineering Group (WREG) (currently the Engineering Applications Branch (EAB)), Environmental Engineering Division (EED), Environmental Laboratory (EL), at the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, MS, sponsored by the Improvement of Operations and Maintenance Techniques (IOMT) Research Program under Work Unit 32433, "Contaminant Release Control During Dredging."

Final technical editing and publication of this report were conducted at WES under the sponsorship of the Dredging Operations Technical Support Program (DOTS), Mr. Thomas R. Patin, Manager. The DOTS Program is managed through the Environmental Effects of Dredging Programs (EEDP), Dr. R. M. Engler, Manager. Mr. Daniel E. Averett, Environmental Restoration Branch (ERB), EED, EL, managed the task area providing for completion of this report. Mr. Joe Wilson was Technical Monitor for Headquarters, U.S. Army Corps of Engineers.

This report was written by Dr. Michael A. Collins, formerly Professor of Civil Engineering, School of Engineering and Applied Sciences, Southern Methodist University, Dallas, TX, and currently with Woodward-Clyde Consultants, Houston, TX. Dr. Donald F. Hayes, formerly with WREG and currently with the Department of Civil Engineering, The University of Utah, Salt Lake City, was the immediate technical supervisor for the project. Administrative supervision was provided by Dr. John J. Ingram, Chief WREG/EAB; Dr. Raymond L. Montgomery, Chief, EED; and Dr. John Harrison, Chief, EL. The IOMT Program Managers were Messrs. E. Clark McNair, Jr., and Robert F. Athow, Hydraulics Laboratory, WES.

Final technical editing of this report was conducted during Fiscal Year 1993 by Dr. Hayes under an interagency support agreement between the University of Nebraska Water Research Center and ERB, and by Mr. Averett. Funding for the technical editing and report preparation was provided by the Dredging Contaminated Sediments: Techniques for Evaluating Resuspension and Release of Contaminants Task Area under the DOTS Program, managed through the Environmental Effects of Dredging Program (EEDP) by Mr. Averett. Technical review of this report was provided by Mr. Averett and Mr. Paul A. Zappi, WREG. Administrative supervision during the

agreement period was provided by Mr. Norman R. Francingues, Chief, ERB; Dr. Raymond L. Montgomery, Chief, EED; and Dr. John Harrison, Chief, EL.

At the time of publication of this report, the Director of WES was Dr. Robert W. Whalin. The Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI To SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
gallons	3.785412	cubic decimeters
square feet	0.09290304	square meters
Note: Source Strength Conversion 1 (milligram/liter) (cubic feet/second) = 0.0283 grams/second		

1 Introduction

Background

Dredging in riverine, lacustrine, and estuarine environments introduces bottom sediments into overlying waters because of imperfect entrainment and incomplete capture of sediments resuspended during the dredging process and the spillage or leakage of sediments during subsequent transportation and disposal of the dredged sediments. Resuspension of bottom sediments and resulting dispersal may pose water quality problems in waters near the dredging operations. Possible release of contaminants adsorbed on sediment particles or residing in interstitial bottom sediment waters, alteration of the physicochemical properties of overlying or nearby waters, and the resettling of sediments in environmentally sensitive waters distant from the dredging operation are a few of the potential environmental problems.

Different types of dredges and dredging operations produce differing amounts of sediment resuspension. Predictions of resuspension and dispersal can provide a basis for improved operation and management of dredging activities. Such estimation requires information about the physical characteristics of the sediment being dredged and the type of dredge being considered and its particular operating characteristics. This report provides a physically based quantitative description of sediment resuspension in the close vicinity of certain types of dredges studied under the U.S. Army Corps of Engineers Improvement of Operations and Maintenance Techniques (IOMT) Research Program.[1]

Purpose

The amount of bottom sediments resuspended in the waters above, below, and around dredges can be described in terms of either (a) sediment concentrations in the vicinity of the dredges during their operation, or (b) rates of resuspended sediment generation at the source. The identification of parameters affecting such sediment concentrations and the characteristics of the

[1] For convenience, abbreviations are listed in Appendix B.

resuspended sediment sources provide insight into the impacts of dredging operations. Such identification should be an integral element in the mathematical description of the entire sediment resuspension, advection, and dispersion process occurring in the general vicinity of operating dredges. This report provides a field-based description of dredging-induced resuspended sediment concentrations and proposes certain mathematical models for dredge-induced resuspended sediment sources.

Scope

This report deals only with resuspension of sediments attributable to the actual dredging process and does not address the effects of sediment disposal or other coincidental factors (such as barge and boat traffic, marine construction, or dredge move-in and setup). Resuspended sediments introduced into the water column in the immediate vicinity of a dredge are subsequently dispersed to points near and far about the dredge by currents, tides, and fluid turbulence. In describing resuspended sediment concentrations and source strengths, this report focuses upon the sediment conditions found in the immediate vicinity of the dredge and considers only incidentally sediment levels at greater distances from the dredge.

Because of the complex factors that influence sediment resuspension, evaluation of field data is imperative for realistic description of the resuspension process and estimation of resuspended sediment source strengths. Field data gathered under the IOMT program are used in this report to describe the sediment concentrations in the close vicinity of dredge types. These concentration data are combined with conceptual models for resuspended sediment source geometries and velocity patterns to estimate sediment source strengths.

Methodology and Limitations

Data sources and characteristics

The present study uses information drawn from several sources (Hayes 1986a, 1986b; Hayes, McLellan, and Truitt 1988; Havis 1988; McLellan et al. 1989) on field studies conducted during the period of 1982 to 1985 at the nine dredging sites listed in Table 1. Depending upon the dredge type and particular site, the data provide information on site and flow conditions, suspended sediment concentrations at various distances and locations about the dredge, and dredge characteristics and operation.

Collection of reliable resuspended sediment data in large-scale field studies, such as the type conducted under the IOMT program, is inherently difficult and subject to many potential sources of both random and systematic error. To effect various analyses, considerable reliance upon temporal and spatial averaging was necessary to reduce data noise. Thus temporally and spatially variable effects arising from external effects such as tides and currents are not specifically identified in the results obtained. However, since the suspended sediment concentrations of interest are near the dredging operation, these factors should be of little importance.

Because of both the character and sometimes limited extent of the database used in various analyses, concentrations developed in this study should be viewed as preliminary until they are verified by additional field studies.

Concentration analysis and source modeling

The field-measured sediment concentrations are analyzed using physical and dimensional reasoning and statistical regression to provide, when possible, a quantitative correlation of resuspended sediment concentrations in the close vicinity of a dredge. Key physical parameters quantifying flow and site conditions, sediment properties, and dredge and dredging characteristics are used in the analysis. Resuspended sediment source models incorporating assumptions as to source geometry and flow patterns are formulated on the basis of physical reasoning, inferences from field data, and descriptions of dredging operations reported in IOMT studies. Source strengths are evaluated using these models in combination with the concentration correlations.

Consequently, resuspended sediment concentrations are based upon actual field data while sediment source strengths, on the other hand, incorporate both field data and assumptions about the features of the resuspension process. The resulting source strength values are mathematical deductions and not directly measurable. Their verification must be indirectly accomplished through comprehensive modeling of the flow field about a dredge. Thus the source strength models proposed in this report must remain speculative until verified by future investigations.

2 Dredge and Dredging Site Features

Resuspension of sediments by dredging is affected by dredge and dredging characteristics, properties of bottom and suspended sediments, and site-specific conditions such as bottom topography, ambient current, and water depth. As a necessary preliminary to consideration of these factors in the dredging-induced sediment resuspension process, this chapter provides a general description of the types of dredges operated during the IOMT studies, a generic description of the flow field about a dredge, a summary of the sediment characteristics at the dredging sites, and a discussion of the features of the sediment concentrations measured during the IOMT dredging studies.

Types of Dredges

Two general types of dredges have been studied under the IOMT program (Table 1): the hydraulic dredge, including cutterhead, matchbox, and dustpan dredge heads on unpropelled dredge plants along with a self-propelled hopper dredge; and the clamshell bucket dredge, including both closed and open bucket designs. Detailed descriptions of these various types of dredges have been provided by Arctic Laboratories et al. (1985), Herbich and Brahme (1991), the U.S. Army Corps of Engineers,[1] Montgomery and Raymond (1984), Peterson (1986), and Raymond (1982, 1984). Generally, hydraulic dredges rely upon a combination of mechanical digging and agitation by a dredgehead to dislodge the sediment and hydraulic suction to lift the dislodged sediment from the bottom. Hopper dredges also rely upon mechanical dislodgement and hydraulic suction as do other hydraulic suction dredges, but differ from other types of hydraulic dredges in that the dredge ship is self-propelled and better able to operate in open water environments. Clamshell bucket dredges rely primarily upon bucket impact, claw gouging and digging, and bucket closure to scoop up and bring bottom sediments to the surface.

[1] U.S. Army Corps of Engineers, Office of Civil Works. (n.d.). "Dredging," Engineering School Manual, The Engineering Center, Fort Belvoir, VA.

Near and Far Flow Fields and Sediment Sources

Sediments removed from the bottom by a dredging operation are either collected and entrained by the dredge, then hydraulically or mechanically removed from the dredging site, or introduced into the water column in the near vicinity of the dredge. Some sediments introduced into the water column and not removed by the dredge may resettle almost immediately in the vicinity of the dredging operation. Other sediments become distributed at various depths throughout the water column. Sediments that are introduced into the water column, that are not carried away by the dredge, and that do not immediately resettle, are considered to be the resuspended sediments. Once resuspended, these sediments are advected and dispersed in varying amounts in the flow field surrounding the dredge. Different types and sizes of dredges, different modes of operation, and different site conditions all result in differing amounts and rates of sediment resuspension.

Two zones can be identified in the dredging area (Hayes[1] 1986a): (a) the near field area immediately surrounding the dredge or dredge head and (b) the far field exterior to and generally surrounding this near field zone. The sediment concentrations in the near field are dominated by the mechanical and hydraulic actions of the dredge and its operation; current- and tidal-induced advection, dispersion, and settling dominate the sediment behavior in the far field.

The amount of resuspended sediment and its distribution in the immediate vicinity of a dredge can be viewed as the result of a source of resuspended sediment located at the dredge or dredgehead in the central core of the near field. This source produces a flux of resuspended sediment into the interior, central zone of the near field. Once in this near field, the resuspended sediment is conveyed outward in some fashion by a combination of advection, dispersion, and turbulence toward the outer edges of the near field area where it merges into a far field plume of suspended sediment.

Site and Sediment Characteristics

Table 1 provides a summary description of the dredging sites studied under the IOMT program. Both inland and coastal areas with a variety of current and salinity conditions are included. Of particular interest are the types of sediment at the sites. Generally, the soils are mixtures of clays and silts, often with high organic content and low specific gravity. The low specific gravity is reflective of the high organic content and sometimes significant amounts of oil and grease in the sediments.

[1] D. F. Hayes. (1987). "Removal of contaminated aquatic sediments using a cutterhead dredge," Unpublished paper, Department of Civil Engineering, Colorado State University, Ft. Collins, CO.

Sediment features that influence the magnitude and distribution of resuspended sediment in the near field water column common to all types of dredging operations are (a) the physical character of the sediments being dredged, as can be quantified by grain size and distribution and specific gravity (relative to the overlying waters) of the sediments, (b) the condition of the in situ sediments as reflected by in situ bulk density, void ratio, and similar physical measures, and (c) the physicochemical characteristics of the sediment or the overlying waters, such as salinity, which might affect colloidal behavior and consequent settling of sediment particles.

In the analyses described in this report, only median grain diameter (as determined by standard grain size analysis methods) and specific gravity of the in situ sediments are used to distinguish between sediment characteristics at the different dredging sites (Table 1); data availability precluded consideration of other factors. Even with restriction to these two physical parameters, however, available site data did not always provide specific information on median grain diameter or specific gravity. In the Calumet River study, a reasonable estimate of these parameters could be made using the data from the nearby Calumet Harbor study. The median grain size at the Savannah River site was estimated, on the other hand, by using data for the Savannah Harbor area presented in a study of dredging sites by Bartos (1977) as summarized by Herbich and Brahme (1991). The median grain size at the Black Rock Harbor site was estimated by extrapolation of partial grain size curves, which did not extend as low as the median grain size. Because of the small median grain size and the sometimes low specific gravity of the dredged sediments, settling velocities are small. (For example, a particle with a median grain size and specific gravity similar to that at the Calumet Harbor site has a fall velocity of 0.02 fps according to Stokes' law, while that of the Savannah Harbor site has only a 0.002-fps fall velocity.)

Sediment Concentration Data

Field data collection procedures

Detailed discussions on the field procedures for collecting and analyzing the suspended sediment data at the various dredging sites can be found in McLellan et al. (1989); Hayes, McLellan, and Truitt (1988); Hayes[1] (1986a); and Vann[2] (1983). In general, water samples were collected from various depths in both the far and near field areas surrounding the dredge during actual dredge operation at various radial distances and angles relative to the

[1] D. F. Hayes. (1987). "Removal of contaminated aquatic sediments using a cutterhead dredge," Unpublished paper, Department of Civil Engineering, Colorado State University, Fort Collins, CO.

[2] R. G. Vann. (n.d.). "James River, Virginia dredging demonstration in contaminated material (kepone), dustpan versus cutterhead," Report, U.S. Army Engineer District, Norfolk, Norfolk, VA.

dredge. At the sites where a cutterhead dredge was operating, the near field samples were collected from a multiple port sampling array located very near the cutterhead on the dredge ladder (see Table 2 for the relative location of sampling tubes on cutterhead dredges; also see Hayes, McLellan, and Truitt (1988) for a detailed description of a cutterhead dredge sampling array).

Background concentrations

Background suspended sediment concentrations (see Table 1 for representative values) were collected in a manner similar to that for the far field concentrations taken during dredging operations. The background samples for the near field were taken in the general vicinity of the actual dredge operation during a period of nondredging but at a time near the near field sampling with the dredge in operation (e.g., on the day immediately before that for which samples were taken during actual dredging). Background concentrations at points near the dredge or dredgehead were estimated by spatial and temporal extrapolation or interpolation of the measured background concentrations. These background concentrations at the various dredging sites are provided in Appendices D, G, I, O, R, T, V, W, and X.

Different techniques were used to estimate the background concentrations, depending upon the character and quantity of background data available. In some cases, a simple average of all measured data was used, while in other cases, horizontal and vertical variations of measured concentrations were considered. At some sites, background concentrations varied little, while at others, varying current and tidal flows resulted in significant variations. In all cases, the background concentrations were determined independently of the concentrations observed during dredging operations.

Dredging-induced concentrations

Bottom sediments disturbed or removed by the mechanical and hydraulic actions of a dredge are either entrained and collected by the dredge, then conveyed to some release or disposal point, or mixed with background suspended sediment to remain in the water column in and around the dredging operation until resettling at some possibly distant point some later time. The difference between measured total suspended solids concentration at a point and the estimated background suspended solids concentration at that same point is assumed to represent the increase in sediment concentration due to the dredging operation. This net concentration difference is the resuspended sediment concentration discussed in this study, for which concentration correlations and resuspended sediment source strengths are provided. Unless otherwise specified, all further mention of resuspended sediment concentration refers to this quantity. These concentrations will frequently be referred to as the observed or measured concentrations; it is recognized that such reference is not precisely true, since only total sediment concentrations were measured in the field. Such reference is made only as a convenience to easily identify the resuspended sediment concentrations computed from measured total concentrations by subtraction of an estimated background concentration.

However, while such a net concentration difference, in view of the level of precision possible in the IOMT field studies to date, is a very appropriate quantity for assessing dredging effects, it is recognized as not necessarily being the most accurate. Background sediments in the water column may have significantly different physical or chemical characteristics from those introduced into the water column by a dredging operation. Resuspended sediments may alter the flocculation characteristics of the background suspended sediment particles and thereby affect their settling behavior. Such effects could be accentuated by salinity levels independent of the dredging operation. Fortunately, such effects can be generally expected to be of secondary importance in the near field area where resuspension is dominated by large mechanical and fluid forces.

3 Resuspended Sediment Concentrations

Near field dredging-induced resuspended sediment concentrations are strongly dependent upon the type of dredge and its operation. Key dimensions, mechanical and hydraulic features, and operating characteristics of a dredge can be used in conjunction with sediment properties to broadly predict the varying levels of resuspended sediment concentrations that may exist in the close vicinity of a dredge. However, actual measurement of suspended sediment concentrations in the near field around an operating dredge is difficult and, for certain types of dredges, potentially dangerous. Consequently, estimation of resuspended sediment concentrations in the central regions of the near field flow zone about a dredge may require inference from concentrations at greater distances rather than being determined by direct measurement.

Near field resuspended sediment concentrations used for this study and the methods used for their determination from field measurements follow. For cutterhead and clamshell bucket dredges, these concentrations are correlated with dredge and dredge operating characteristics and sediment properties.

Cutterhead Suction Dredges

Three studies (Table 1) have specifically examined sediment resuspension by cutterhead dredges. The conditions at the sites and the operating conditions of the dredges at the three sites, collectively, span a wide range of conditions, thus making these studies potentially very useful for examination of a variety of factors influencing sediment resuspension. However, data collection in the earlier two of the studies (i.e., the James River and the Savannah River studies) was not as complete nor as controlled as in the later Calumet Harbor study. As a result, in comparison to the Calumet Harbor data, considerable apparent random error exists in the data for both the James River and the Savannah River studies. Conclusions based solely upon these data should therefore be viewed with caution. Conversely, more confidence can be placed in deductions about resuspended sediment concentrations based upon the Calumet Harbor data.

Concentrations at cutterhead

Cutterhead dredges agitate, loosen, and dislodge bottom sediments with a combination of mechanical digging and gouging by a multiblade, rotating cutterhead. Hydraulic suction forces draw sediment-enriched waters upward through and around the cutterhead blades into a suction pipe extending along the cutterhead ladder arm. Sediment resuspension results from the incomplete entrainment of the dislodged sediments. Conceptually, the source of resuspended sediments is the cutterhead itself.

Perfectly designed and operated cutters will introduce a sediment slurry that will be completely entrained by the flow to the dredge pump. However, spatially varying sediment properties and cutter operations inevitably lead to a sediment slurry that the pump cannot handle, resulting in sediment resuspension or release.

Suspended sediment concentrations were directly sampled using tubes at several points in the immediate vicinity of the cutterhead to withdraw samples. The number of sampling tubes varied from one to six, depending upon the sampling device design and condition. Sampling tubes sometimes became clogged with sediment, rendering them temporarily inoperative, as evidenced by abnormally large suspended sediment concentrations being measured. To avoid inclusion of data from such potentially unrepresentative data, outliers in the concentration data were statistically identified and discarded by excluding data more than two standard deviations from the mean of a data set; roughly 10 percent of the data at the Savannah River and James River sites were discarded. The remaining concentrations measured by the sampling tubes at the cutterhead were arithmetically averaged, after adjusting for background concentrations, to approximate a spatial average concentration at the cutterhead source for each set of conditions at the particular time of the sampling. Total suspended sediment concentrations (i.e., concentrations before subtraction of background concentrations) along with dredge operating characteristics are given in Appendices F, H, and M for the cutterhead dredges at the James River, Savannah River, and Calumet Harbor sites, respectively. Background concentrations for the James River site are given in Appendices D and F, while background concentrations for the Savannah River and Calumet Harbor sites are given in Appendices G and I, respectively. Appendix L provides additional operating features of the dredge at the Calumet Harbor site.

For the Savannah River and James River sites, the concentration data are values measured at various particular times during the course of the field study as dredge operating conditions varied. For the Calumet Harbor site, however, the data represent averages (as given by Hayes (1986a) and Hayes, McLellan, and Truitt (1988)) over a period of time when operating conditions were essentially constant; because of the well-controlled dredge operating conditions during the course of the Calumet Harbor study, such averages are meaningful. The operating conditions at the Savannah River and James River sites were not as well defined. In addition, since cutterhead swing speed and intake velocity data were incomplete for the James River site, estimated average values for these parameters, which do not reflect their actual variation, were used for analysis. In particular, the ladder arm swing speed at the James River site had to be estimated from dredge dimensions and reported average ladder arm swing times in the port and starboard directions. Hayes (1986a) previously developed a simple geometric model relating swing speed and cutterhead path to dredge dimensions; this model was applied to the swing time data at the James River site. This considerably reduced the ability to distinguish the dependence of resuspended sediment concentration upon various operating conditions at the James River site.

Factors influencing resuspension

Previous investigators have identified or suggested factors that influence the amount of sediments introduced into the water column immediately surrounding the cutterhead (Hayes (1986a) provides a concise review of cutterhead dredge studies). In addition to the characteristics of the sediments being dredged, the water depth in which the dredging is taking place, and the fluid motion in the general area of the dredge operation, several factors are specifically characteristic of cutterhead dredges that influence the amount of resuspension.

The speed and turbulence of the waters, and thus their potential for both eroding and scattering sediments, surrounding the dredge cutterhead are affected by the rotation of the cutterhead blades and the swing speed of the cutterhead ladder on which the cutterhead is supported. Variations in either of these speeds can be expected to influence the amount of resuspension. On the other hand, background velocities in the general vicinity of the dredge are not expected to significantly influence the amount of resuspension; the velocity field around the cutterhead and cutterhead ladder is a localized velocity field largely determined by the motion of the swinging cutterhead ladder.

Furthermore, previous investigators (e.g., Hayes, McLellan, and Truitt, 1988) have generally found that the direction of the ladder swing relative to the cutterhead blade rotation is also important, with more resuspension occurring when the ladder swing is in the same direction as the tangential velocity of cutterhead blades at their highest point. When the tangential velocity of the cutterhead blades at their highest point is in the same direction as the ladder swing, the cutterhead is "overcutting," i.e., the cutterhead blades are rotating downward into the mudline and into the yet-undredged sediments toward which the cutterhead ladder is advancing. When the ladder swing opposes the tangetial velocity of the cutterhead blades at their highest point, the cutterhead is "undercutting," i.e., the cutterhead blades are rotating upward and away from the sediments being dredged and away from undredged sediments toward which the cutterhead ladder is advancing.

An explanation for the higher resuspended sediment concentrations that occur during overcutting can be provided: a primary source of finer grained resuspended sediments is the residual sediments clinging to the cutterhead blades as they break the level of the mudline near the top of the cutterhead. These residual sediments are washed off the blades by the fluid motions over and around the blades above the level of the mudline. Near the top of the cutterhead above the mudline level, the tangential velocity of the blades will be in the same direction as the swing velocity when overcutting occurs. Thus the net blade velocity relative to the overlying waters is the summation of the tangential velocity of the cutterhead blades and the ladder swing speed; when undercutting occurs, the net velocity is the difference between these same two velocities. Consequently, the cutterhead blades experience a higher shearing velocity during the overcutting phase of the swing than during the undercutting phase.

The effects of the residual sediment clinging to the cutterhead blades and being subsequently washed off by the relative fluid motion past the cutterhead can be expected to be more pronounced in silt and clay sediments; the cohesiveness of such sediments promotes clinging of sediments to the cutterhead blades. Such effects may not be as pronounced in noncohesive sediments. The sediments at the cutterhead dredge sites in this study were predominantly silt and clay, as evidenced by their median grain size (Table 1); consequently, this description of the washoff phenomenon is consistent with the field conditions in this study.

These effects can be quantified by the introduction of a cutterhead ladder arm swing speed V_s and a tangential velocity (at the top of the cutterhead) of the cutterhead blades V_c computed from the angular velocity and maximum radius of the cutterhead.[1] When the cutterhead is undercutting, the net velocity V_t characteristic of the fluid motion tending to wash sediments off the cutterhead is $V_t = V_c - V_s$; when overcutting, the characteristic velocity is $V_t = V_c + V_s$.

On the other hand, an increase in the rate at which sediment-laden waters are drawn into the dredge suction pipe will tend to reduce the amount of sediments found around the cutterhead. A meaningful and useful characterization of this effect has been proposed by Hayes (1986a) and Hayes, McLellan, and Truitt (1988). The cutterhead is assumed to be surrounded, in view of the shape of typical cutterheads, by one-half of a prolate spheroid (i.e., a semi-ellipsoid) formed by the rotation of an ellipse about its major axis, with major and minor axes equal to the length and the maximum radius, respectively, of the cutterhead. The suction discharge passing across this surface determines an average characteristic cutterhead intake suction velocity V_i. In addition, the diameter of a sphere whose volume is equal to the volume of the total ellipsoid defines a characteristic size, L, of the cutterhead.

The degree of cutterhead burial in the bottom sediments as the cutterhead is swung back and forth has also been identified as a significant factor influencing resuspension. Previous studies suggest that full burial, with all other

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[1] For convenience, symbols are listed in the notation (Appendix A).

factors being equal, results in the least resuspension. Less than full burial (i.e., partial cutting) apparently increases resuspension, as does more than full burial (i.e., buried cutting). The reason for increased resuspension during partial cutting can be explained by the fact that in partial cutting more of the cutterhead blades are exposed above the mudline; more exposure of the blades allows more opportunity for washoff of sediments clinging to the cutterhead blades. The increase in resuspension because of buried cutting is understandable (though difficult to evaluate), because buried cutting contributes to sloughing and cave-in along the dredging path.

The Savannah River study had partial- and buried-cut but no full-cut operation, while the Calumet Harbor and the James River studies had only full cuts (Table 2). Thus, as will be seen below, the Calumet Harbor and James River studies are used to provide the primary insight into full-cut operations. The Savannah River study data are used to provide a preliminary quantification of the increased resuspension of sediments induced by partial- and buried-cut dredging.

Resuspended sediment concentration model

Hayes, in earlier studies of the Calumet Harbor site (Hayes 1986a; Hayes, McLellan, and Truitt 1988), found a good correlation of resuspended sediment levels with the dimensionless parameters V_s/V_i and V_t/V_i. The dependence evidenced in this correlation was consistent with physical reasoning as to the expected impacts of the various velocity parameters V_s, V_t, and V_i. As discussed above, more confidence could be placed in the field data from the Calumet Harbor site than in the field data from the Savannah River and James River sites. Thus it was considered important that the basic behavior demonstrated by the correlation found by Hayes (1986a) for the Calumet Harbor study be reflected in any model for resuspended sediment concentration that might incorporate data from all three cutterhead dredge study sites. Hayes' previously found result was therefore a starting point for correlation of data from all three cutterhead dredge sites examined in this study.

Using dimensionless analysis, Hayes (1986a) was able to relate resuspended sediment levels at the Calumet Harbor site to powers of the dimensionless parameters V_s/V_i and V_t/V_i; reanalysis of Hayes' data confirmed this basic dependence. For the Calumet Harbor study the resuspended sediment concentrations can be represented by

$$C/(\rho \times 10^{-6}) = 10^{u}(V_s/V_i)^{v}\ (V_t/V_i)^{w} \tag{1}$$

in which

C = concentration of resuspended sediment, g/ℓ

ρ = density of waters above the mudline (assumed to be 1 g/cm^3 for calculations in this study), g/cm^3

V_s = swing speed, ft/sec

V_i = intake suction velocity through approximating semi-ellipsoid surface, ft/sec

V_t = tangential speed of cutterhead, ft/sec

and u, v, and w are regression coefficients found by linear regression of the logarithmic form of Equation 1 on the resuspended sediment concentrations at the Calumet Harbor site. Regression analysis on the 12 data sets for the Calumet Harbor site yields $v = 2.848$ and $w = 1.022$ (similar to the values found by Hayes (1986a) and $u = -1.050$ with a correlation coefficient r^2 of 0.72. For the 12 sets of data used to find u, u has a standard deviation of 0.160. (Note: since w is close to 1, it might seem desirable to assume $w = 1$ and determine by linear regression a revised value of v. When this is done, however, the correlation coefficient drops to 0.64. Since it is considered more important to maintain as high a correlation as possible, the original value of $w = 1.022$ is maintained in subsequent calculations.)

To utilize the results of the Calumet Harbor study for other dredging sites, it is assumed that the concentration dependence upon V_s/V_i and V_t/V_i exhibited by Equation 1 at the Calumet Harbor site is valid for all cutterhead dredging, irrespective of the site or cutting mode. On the other hand, physical and dimensional reasoning suggests that the magnitude of the coefficient u will likely vary from site to site because of such factors as the type of cutting, the size of the cutterhead, the characteristics of the bottom sediments, and possibly the depth of water above the cutterhead. To reflect this possible variation in u, Equation 1 is restated as

$$C/(\rho \times 10^{-6}) = F(V_s/V_i)^v \, (V_t/V_i)^w \tag{2}$$

in which

$$F = F_F \, F_D \tag{3}$$

F_F and F_D are full-cut and nonfull-cut dredging parameters, respectively, defined such that

$$u = \log_{10}(F) = \log_{10}(F_F) + \log_{10}(F_D) \tag{4a}$$

$$F_D = 1, \textit{ for full-cut dredging} \tag{4b}$$

$$F_D > 1, \textit{ for nonfull-cut dredging} \tag{4c}$$

and such that F_F is independent of the type of cutting being used. Thus F_D is a factor that accounts for the type of dredging, while F_F is a factor that accounts for dredging effects other than those arising from variations in the type of cutting.

Development of dredging parameter F_F and F_D

At a particular dredging site with only full-cut dredging, such as the James River or the Calumet Harbor dredging site, $F_D = 1$ and F_F is some constant. Furthermore, since the analysis of the Calumet Harbor data isolated the dependence of V_s, V_t, and V_i and this dependence is assumed to exist for other cutterhead dredging sites, the parameter F_F cannot involve a dependence upon the kinematic parameters V_s, V_t, and V_i. A dependence upon these parameters could exist in the parameter F_D, but it is assumed that it does not. Consequently, F_F must depend upon nonkinematic parameters.

Dimensional reasoning suggests that F_F should be a function of various dimensionless groups quantifying the geometric differences between cutterhead dredging at those sites with full-cut dredging. The only readily quantified differences at the two sites for which full cuts were used, i.e, the Calumet Harbor and James River sites, that seem pertinent to the resuspended sediment concentrations in the immediate vicinity of the cutterhead are the characteristic cutterhead size L (Table 3) and the median grain diameter d of the dredged sediments (Table 1). The depth of overlying water might be important in cases of very shallow depth where the cutterhead size and water depth are of similar size, but for the Calumet Harbor and the James River sites the water depths were several times larger than the cutterhead diameter. Such depths would not seem physically significant in influencing the resuspended sediment concentrations in the immediate vicinity of the cutterhead. Thus the only quantifiable dimensionless parameter upon which the dredging factor F_F can depend is the parameter L/d; therefore

$$F_F = f(L/d) \tag{5}$$

Values of L/d are listed in Table 4.

F_D may also have a dependence upon L/d. However, since only the Savannah River site had nonfull-cut dredging and L/d is a constant for a particular dredging site, such dependence cannot be identified even if it exists. The only dependence that might be identified is that which characterizes the differences between types of cutting modes.

The identification of the dependence of F_F upon L/d and of F_D upon the type of cut would ideally be determined by simultaneous use of data from all three cutterhead sites. However, this is not possible since the Calumet Harbor and James River dredging were full-cut operations while the dredging at the Savannah River site used buried and partial cutting but no full cutting. Thus to identify, at least approximately, the dependence of F_F and F_D upon L/d and the type of cut, respectively, it is necessary to decompose the identification process into an examination of the effects of nonfull cuts and an examination of the effects of L/d.

Effects of cutterhead and sediment size

A representative value of F for a particular site and dredge type can be determined by computing the mean value of u and setting F equal to the antilog of this mean value. That is, a representative value of F is the geometric mean of the individual values of F for the same dredge type at a particular site. To make this computation while preserving the dependence of concentration on V_s/V_i and V_t/V_i evidenced in Equation 1, u is defined by

$$u = \log_{10} [C/(\rho \times 10^{-6})] - v \log_{10} (V_s/V_i) - w \log_{10} (V_t/V_i) \qquad (6)$$

and computed from the various data for resuspended sediment concentrations for each dredge type at each site using the values of v and w found for the Calumet Harbor site (Table 4). An average value of u is then computed for each type of dredging at each site. The values of u and their standard deviations found at the James River and the Savannah River sites are summarized in Table 4 as are the values of F corresponding to these mean u. The larger variation in u implied by the larger standard deviations at the James River and Savannah River sites (in comparison to that for the Calumet Harbor site) is considered indicative of the more controlled conditions under which the study at the Calumet Harbor site was conducted.

Since, furthermore, the Calumet Harbor and James River studies used full-cut dredging, the values of F for these two sites can be used to preliminarily identify a dependence of F_F upon dredge and sediment size as embodied in the parameter L/d since $F = F_F$ for full cuts; the effects of partial or buried cutting are used, as described below, to refine this preliminarily identified dependence.

The values of L/d and F_F for the Calumet Harbor and James River sites (Table 4) suggest that F_F increases with L/d; such a variation is physically plausible. The larger L/d, the larger the cutterhead size in comparison to the sediments being dredged and the more resuspension that might be expected; the larger F_F, the higher the resuspended sediment concentration. However, since the Calumet Harbor and the James River sites provide only two data points to define this variation, little more can be said about this variation. Consequently, the Savannah River data for partial and buried cutting are needed to further refine this variation. To accomplish this, it is useful to attempt to quantify the effects that partial and buried cuts have on full cutting as suggested by the Savannah River data.

Effects of type of cut

As previously discussed, it is expected that buried- or partial-cut dredging will increase the resuspended sediment concentrations above those for full-cut dredging. This increase in resuspended sediment concentration due to nonfull cutting is formally described by the parameter F_D, where

$$F_D = f\,(P;\ D_m/D_{ch}) \tag{7}$$

where

P = degree of cutterhead penetration for a partial cut

D_m = depth of cut for buried cutting

D_{ch} = maximum diameter of the cutterhead

thus D_m/D_{ch} is the relative depth of cutterhead burial in a buried cut. Precise definitions of P and D_m/D_{ch} are provided below. Other factors may affect F_D, but P and D_m/D_{ch} are the only readily quantified factors distinguishing the types of cuts at the Savannah River site, the only site with nonfull cuts; thus F_D is presumed to depend only on these parameters.

In partial-cut dredging, the increase in resuspended sediment concentration is viewed as the result of the increased sediment washoff from more exposure of the cutterhead blades (in comparison to that for full-cut dredging). In general for a partial cut, as illustrated in Figure 1, the cutterhead will penetrate a vertical distance d_f below the original mudline. The value of d_f assumes a maximum at the point where the partial cut becomes a full cut; at this point $d_f = D_f$. Because the cutterhead shape is approximated as a semi-ellipsoid with maximum diameter D_{ch} and length L_{ch}, D_f can be approximated as (Appendix C)

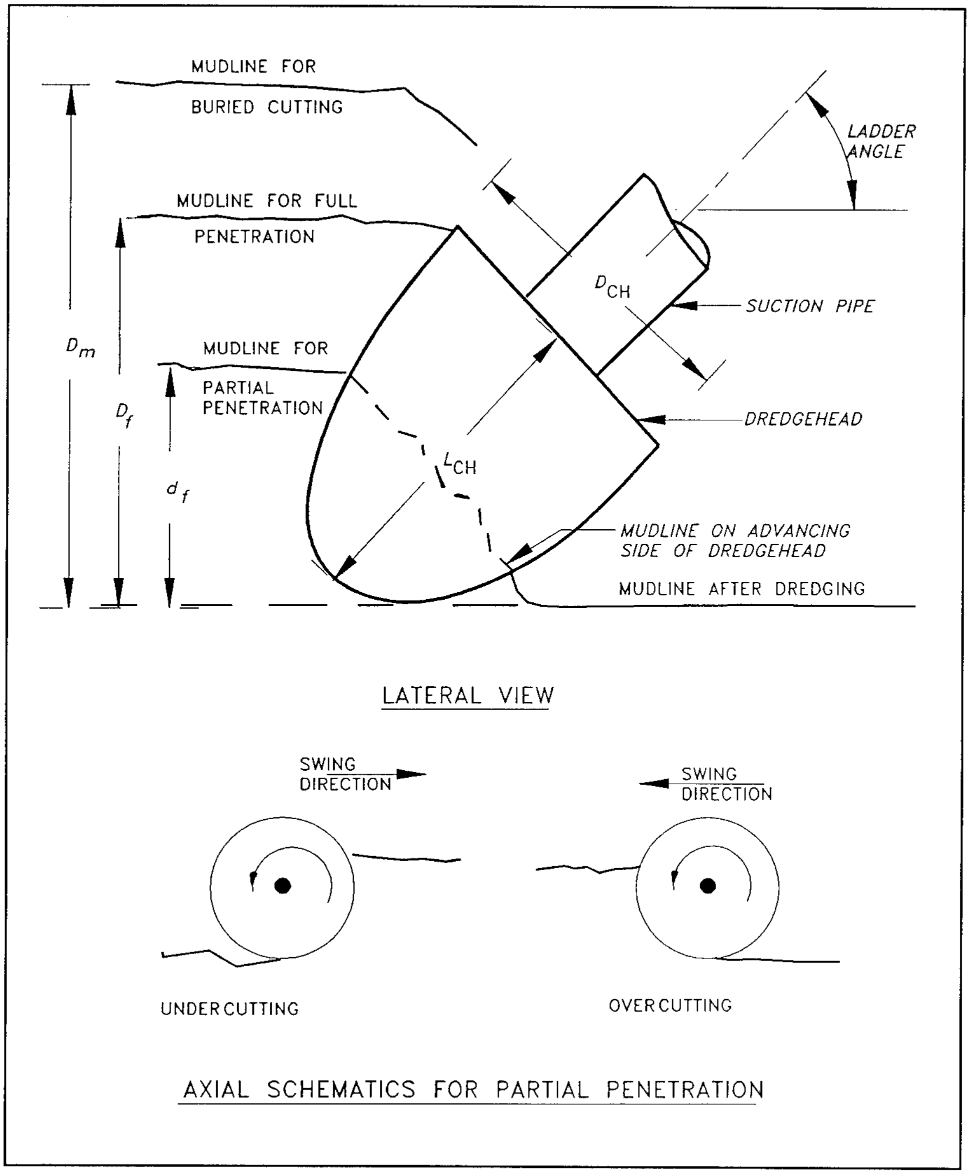

Figure 1. Schematics of cutterhead burial for various types of cuts

$$D_f = (D_{ch}/2) \cos \theta \; (1 + 1/q') \tag{8a}$$

in which

$$1/q' = \left[1 + (2 \tan \theta \; L_{ch}/D_{ch})^2\right]^{1/2} \tag{8b}$$

where θ is the angle the ladder arm supporting the cutterhead makes with the horizontal and q' is the dimensionless y distance to point of tangency of cutterhead ellipse with penetration line. The relative penetration P is then given by

$$P = d_f/D_f \tag{9}$$

where P will obtain a maximum of 1 for a full cut.

The primary mechanism for producing increased resuspended sediment concentrations in buried cutting is not viewed, however, as one of washoff. Rather, it is viewed as the result of bank sloughing and cave-in around the cutterhead. In buried cutting the cutterhead is positioned so that the bottom of the cutterhead is a distance D_m below the mudline, where $D_m > D_f$ (Figure 1). The cutting and removal of bottom sediment material by the cutterhead cause sediments above the cutterhead to fall and slough into and around the cutterhead. These falling and sloughing materials overload the dredge suction capabilities and allow sediments to remain in the waters about the cutterhead, thereby increasing the resuspended sediment concentration levels. These effects are expected to increase as the dimensionless burial parameter D_m/D_{ch} becomes larger.

Since the resuspension increases for depths of cutterhead submergence in the bottom sediments both larger and smaller than D_f, it is convenient to define the dimensionless cutterhead submergence depth D by

$$D = P \qquad \textit{where} \qquad 0 \le P \le 1 \tag{10a}$$

for partial cuts and

$$D = D_m/D_f \qquad \textit{where} \qquad D_m \ge D_f \tag{10b}$$

for buried cuts. Thus,

$$F_D(P;\ D_m/D_{ch}) = F_D(D) \qquad \textit{and} \qquad D \ge 0 \tag{11}$$

and since $F_F = f(L/d)$ and $F = F_F F_D$

$$F = f(L/d;\ D). \tag{12}$$

Note that F is undefined for $D < 0$.

F_D is assumed to have the general form

$$F_D = 1 + (F_D)_w + (F_D)_b \tag{13}$$

in which $(F_D)_w$ is the resuspension function describing the effects of sediment washoff from the cutterhead blades for partial cuts and $(F_D)_b$ is the resuspension function describing the effects of bank sloughing and cave-in on resuspension for buried cuts. The general characteristics expected and therefore proposed for $(F_D)_w$ and $(F_D)_b$ are

$$(F_D)_w = 0 \qquad for \qquad D \geq 1 \tag{14a}$$

$$(F_D)_w > 0 \qquad for \qquad 0 < D < 1 \tag{14b}$$

$$(F_D)_b = 0 \qquad for \qquad D \leq 1 \tag{14c}$$

and

$$(F_D)_b(D > 1) > (F_D)_b(D = 1) \tag{14d}$$

Also, $(F_D)_w$ decreases monotonically with increases in D for $0 \leq D \leq 1$ and $(F_D)_b$ increases monotonically with increasing D for $D > 1$. $(F_D)_w$ and $(F_D)_b$ are undefined for $D < 0$. Also note that for a full cut (i.e., $D = 1$), $(F_D)_w = (F_D)_b = 0$; therefore Equations 13 and 14 imply that when $D = 1$ (full-cut dredging)

$$F_D = 1 + 0 + 0 = 1 \tag{15}$$

The constraints of Equations 14 and 15 on F_D can be examined in light of the data for the Savannah River site. For this site, the penetration depth d_f for the cutterhead in partial cut operations was in the range of 1 to 3 ft, while the ladder angle θ was approximately 45 deg. Thus, using Equations 8, 9, and 10, D_f = 6.24 ft and D was therefore in the range of 0.1 to 0.5. Since the average u for the partial cuts at the Savannah River site is -0.556, $F = F_F F_D$ is computed to be 0.278; thus

$$F/F_F = F_D = 1 + (F_D)_w + (F_D)_b = 1 + (F_D)_w + 0 = 0.278/F_F \quad (16)$$

or

$$(F_D)_w = 0.278/F_F - 1 \quad (17)$$

for D in the range of 0.1 to 0.5.

For buried cuts at the Savannah River site, the cutterhead was buried to a depth of approximately 20 ft. Thus $D = D_m/D_f$ = 20 ft/4.93 ft = 3.2. Since the average u for the buried cuts at the Savannah River site is 1.229, F = 16.94. Thus, in a manner similar to that for the partial cuts,

$$(F_D)_b = 16.94/F_F - 1 \quad (18)$$

for D approximately 3.2.

Actual values of $(F_D)_w$ and $(F_D)_b$ for the two cutting modes at the Savannah River site require an estimate of F_F for the Savannah River site. This estimate is provided in the following section.

Full-cut dredging function

The full-cut dredging parameter, F_F, has been deduced previously to be a function of L/d; two values for this function have been identified using the data from the Calumet Harbor and the James River sites (Table 5). Estimates of F_F for the Savannah River site can be provided by (a) an examination of the potential range for F_F and (b) a physically based model for partial-cut dredging. Estimates using both these techniques are provided below. These estimates then allow an approximation to F_F as a function of L/d to be deduced.

Fortuitously, L/d for the Savannah River site is intermediate between the L/d's for the Calumet Harbor and the James River sites. Since F_F (which equals F for full cuts) is physically expected to increase with increasing L/d, F_F at the Savannah River site must be greater than the F_F at the Calumet Harbor site and less than the F_F at the James River site; i.e.,

$$F_F(L/d = 27{,}928) < F_F(L/d = 94223) < F_F(L/d) = 123{,}680 \quad (19)$$

Therefore, using the data of Table 4

$$0.0892 < F_F(L/d = 94{,}223) < 82.1 \quad (20)$$

In addition, since $F = F_F F_D > 1$ for nonfull cuts, the buried-cut results for the Savannah River site require that

$$F_F < 16.94 \quad (21)$$

while the partial-cut results for the Savannah River site indicate the more restrictive condition

$$F_F < 0.278 \quad (22)$$

Combining these limits yields the condition

$$0.0892 < F_F(L/d = 94{,}223) < 0.278 \quad (23)$$

which is illustrated in Figure 2.

The discrete points for F_F provided by the Calumet Harbor and the James River sites plus the range of values for F_F provided by the Savannah River site provide a means to estimate a continuous function for F_F; such a function is illustrated in Figure 2. A precise equation for this function is developed below. However, this equation must be applied cautiously because of the limited data used in its development.

To provide an estimate of a specific value of F_F for the Savannah River site, a physically based model for $(F_D)_w$ can be formulated. It is recognized that such a model will be unverified; however, this model does provide not only a physically reasonable value for $(F_D)_w$ but a value of F_F that is also consistent with the previously defined limits on F_F.

In a partial-cut operation, the increase in resuspended sediment concentration is viewed, as previously discussed, as the result of increased cutterhead surface area available for sediment washoff. The area over which the sediment washoff occurs is taken as the exposed cutterhead surface area not

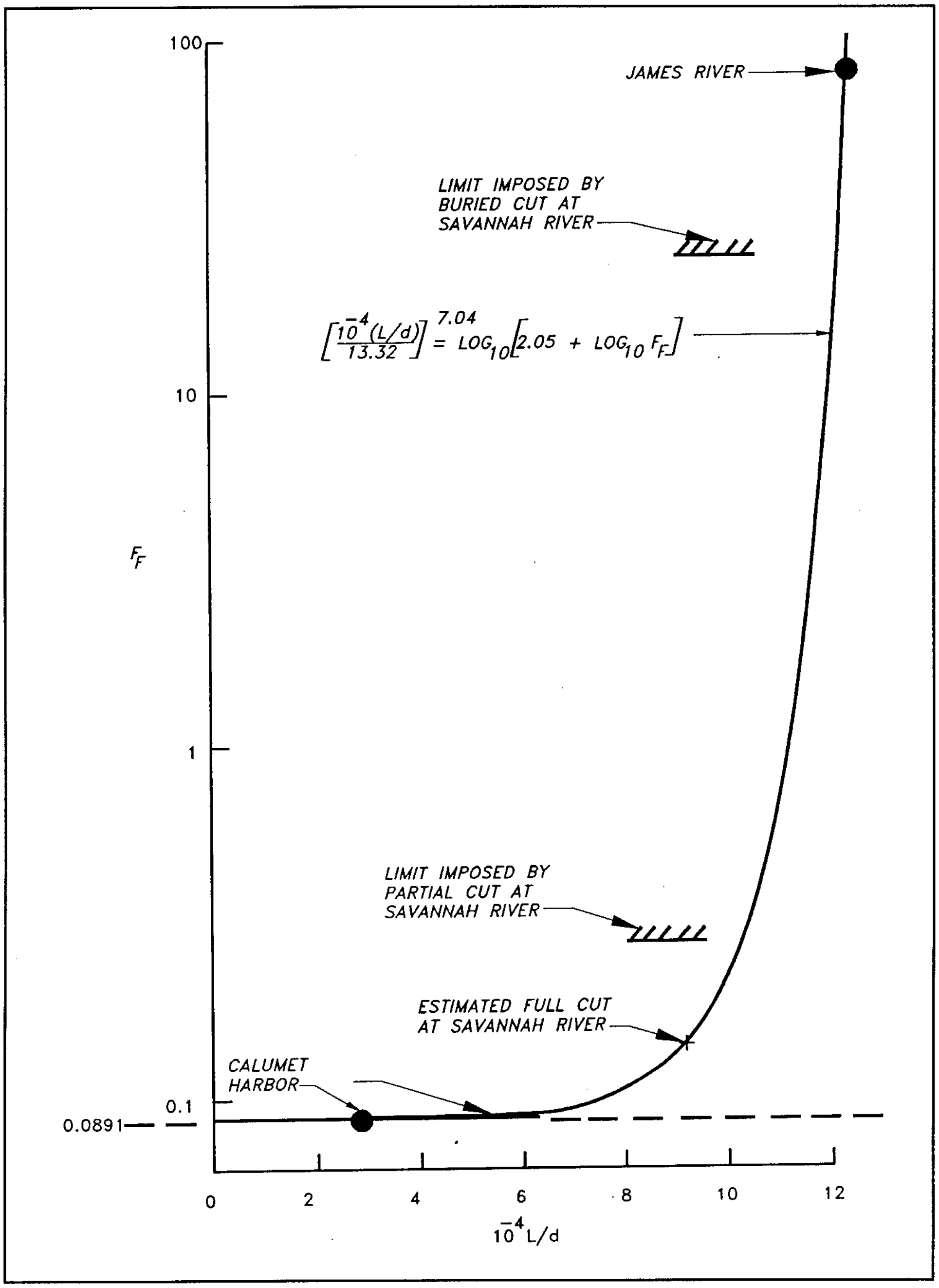

Figure 2. Full-cut dredging function F_f for cutterhead dredge

submerged in the bottom sediments being dredged. This exposed area is a fraction of the source volume surface available for sediment generation $F_c < 1$ of the total cutterhead surface area, A_{ch}. The area exposed on the side of the cutterhead advancing into the sediments (i.e., swinging into the sediments) is different from that on the opposite, nonadvancing side of the cutterhead, as illustrated in Figure 1. Let the fraction of surface area exposed on the advancing side of the cutterhead be F_a and the fraction on the nonadvancing side be F_n , where

$$F_c = F_a + F_n \tag{24}$$

and $F_a \leq F_n$, $F_a \leq 0.5$, and $F_n \leq 0.5$. The fraction of nonexposed submerged surface areas on each side of the cutterhead is therefore, in general, $0.5 - F_a$ and $0.5 - F_n$. On the nonadvancing side of the cutterhead it is assumed, however, that the entire cutterhead surface is exposed, and thus $F_n = 0.5$. On the advancing side of the cutterhead, the bottom sediments are assumed to extend a vertical height d_f above the low point of the cutterhead and slope downward across the cutterhead perpendicular to the axis of cutterhead rotation as shown in Figure 1. As a consequence $0.5 - F_a$ is

$$0.5 - F_a = 0.5\ a_z \tag{25}$$

in which, as detailed in Appendix C and by replacing P with D in accord with Equation 10a, a_z, the fraction of cutterhead semi-ellipsoid surface submerged below mudline, is approximated by

$$az = 1 - \left[1 - \left(2_{y_p}/D_{ch}\right)^2\right]^{1/2} \qquad for \qquad D \geq P_o \tag{26a}$$

and

$$a_z = 0 \qquad for \qquad D < P_o \tag{26b}$$

in which

$$2_{y_p}/D_{ch} = q'\ [D(q' + 1) - 1] + \Big((1 - q'2)\ \{1 - [D\ (q' + 1) - 1]^2\}\Big)^{1/2} \tag{26c}$$

$$P_o = [1/(1 + q')] - [(1 - q')/(1 + q')]^{1/2} \tag{26d}$$

Thus, considering both sides of the cutterhead it follows that

$$F_c = 1 - 0.5\ a_z \tag{27}$$

If the increase in resuspended sediment concentration from partial cutting is presumed to be proportional to the increase in exposed surface in a partial cut,

$$(F_D)_w = F_c/F_{c(D=1)} - 1 = 1 - az \tag{28}$$

Applying the model of Equations 24 through 28 to the Savannah River data, the following is obtained for $\theta = 45$ deg, $D = 0.3$ (the average of the range of 0.1 to 0.5 identified above), and $D_f = 6.24$ ft as previously determined: $q' = 0.5145$, $P_o = 0.094$, $2_{yp}/D_{ch} = 0.4378$, $az = 0.101$, $F_c = 0.950$, $(F_D)_w = 0.899$, and $F_D = 1.899$. These values of F_D and $(F_D)_w$ are physically realistic.

Furthermore, if $F_D = 1.899$, it follows from Equation 3 and the data of Table 4 that for the Savannah River data $F_F = F/F_D = 0.278/1.899 = 0.1464 \approx 0.15$. This value for F_F falls nicely within the bounds identified for F_F. Thus the above-described model for $(F_D)_w$ appears to be reasonable.

If a value of $F_F = 0.15$ is accepted as an estimate for F_F for the Savannah River data, an empirical curve can be fitted to the three data points for F_F now provided by the Calumet Harbor, the Savannah River, and the James River data. With only three data points, the data are closely fitted by the equation

$$[(10^{-4}\ L/d)/13.3]^{7.04} = \log_{10}[\log_{10}(F_F) + 2.05] \tag{29a}$$

or equivalently

$$\log_{10}(F_F) = 10^{[10^{-4}(L/d)/13.32]^{7.04}} - 2.05 \tag{29b}$$

With F_F now estimated to be 0.15, Equation 18 can be used to determine that $(F_D)_b = 111.9$. The values of $(F_D)_w = F_D = 0.899$ for $D = 0.3$ and $(F_D)_b = F_D = 111.9$ for $D = 3.2$ along with $F_D = 0$ for $D = 1$ allow an approximate functional form for F_D to be identified, as shown by the curve in Figure 3. The empirical curve of Figure 3 is given by the equation

$$F_D = 1.9039(D - 1)^2 + 0.4116(D - 1)^7 \tag{30}$$

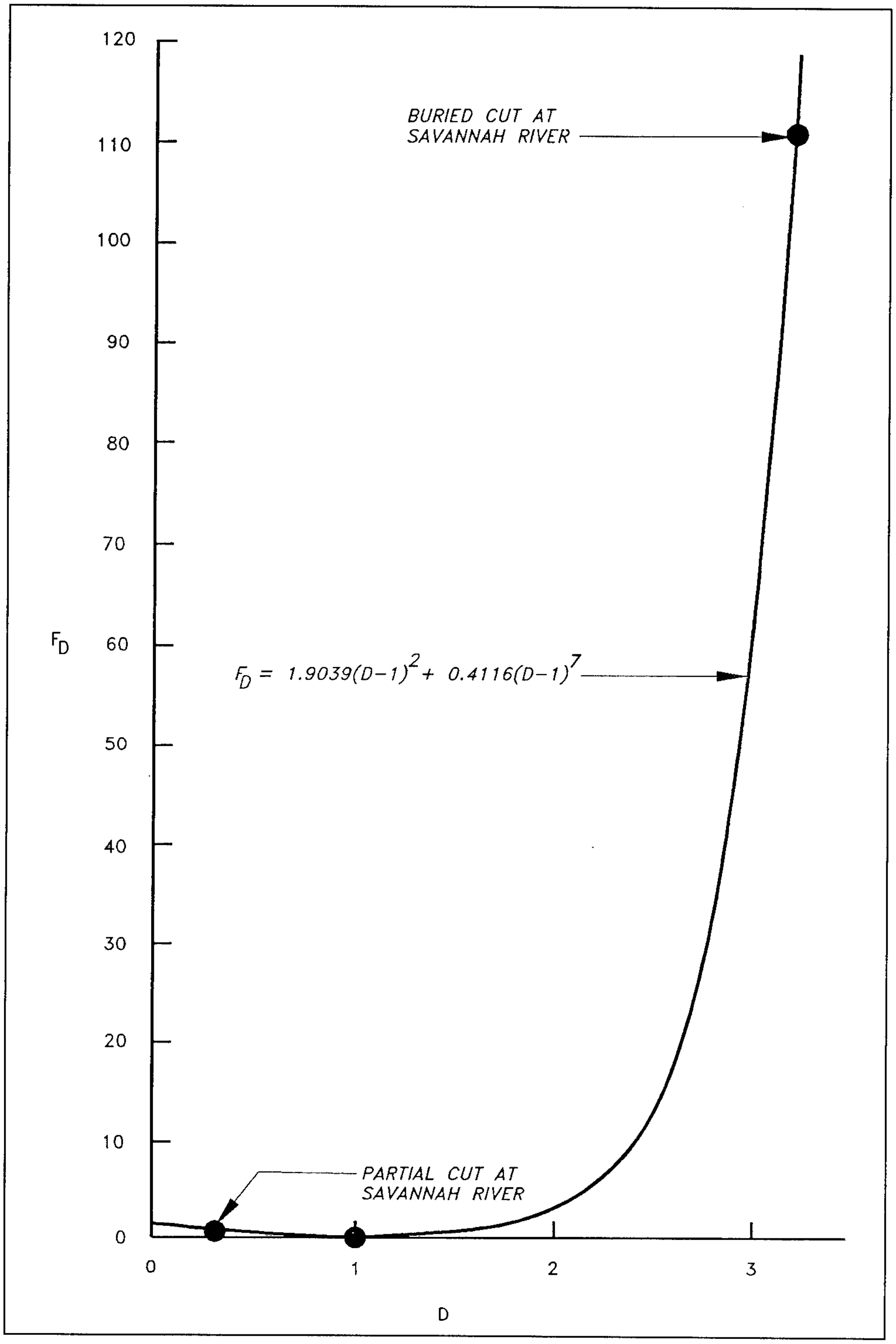

Figure 3. Cutterhead cutting type function F_D

Equations 29 and 30 illustrate the general relationships between important dredging and sediment parameters but should be applied cautiously to other dredging sites. However, the use of these equations must be tempered considerably by the limited data upon which they are based and their mathematical characteristics. Values of F_F generated using Equation 29b increase dramatically with small changes in the median grain diameter d. Similarly, Equation 30 responds dramatically to values of D in excess of 2. Consequently, these equations can predict large variations in predicted suspended sediment concentrations with small changes in these variables.

General data correlation

With an estimated value of F_D for the Savannah River data provided by Equation 30 it is possible to infer what the resuspended sediment concentrations at the Savannah River site would presumably have been if a full cut had been used but all other factors had remained the same. If the Savannah River data are adjusted to reflect full-cut dredging, then collectively the Calumet Harbor, the James River, and the adjusted Savannah River data provide a combined set of data to assess the ability of the full-cut model to generally describe the resuspended sediment concentrations induced by a cutterhead dredge.

To adjust the Savannah River data, all partial-cut concentrations are reduced by the factor $1 + (F_D)_w = 1.899$; all buried cut concentrations are reduced by the factor $1 + (F_D)_b = 112.9$. The F_F factor for the resulting data is 0.15, as computed above, from which $u = -0.824$ is determined (Table 4). These resulting data, along with the appropriate V_s, V_t, and V_i, are combined with the Calumet Harbor data (with $F_F = 0.0892$) and the James River data (with $F_F = 87.3$), each with their various V_s, V_t, and V_i values, to provide a general data set against which Equation 2, for a full cut, can be tested.

The observed resuspended concentrations (or, in the case of the Savannah River data, the adjusted concentrations) are plotted against the concentrations predicted by Equation 2 in Figure 4. The straight line through the data indicates the line of perfect fit. The degree of scatter about this line of perfect fit can be quantified by computing the correlation coefficient r^2 and the standard error in estimate between the computed and observed data, treating the predicted values of the logarithm of concentration as the independent variable and the observed values of the logarithm of concentration as the dependent variable in a simple linear regression. Computed correlation coefficients and standard errors of estimate for the logarithms of the concentrations are listed in Table 5 for all the data and various subsets of the data. The overall correlation coefficient r^2 for the entire data set is 0.556. Subsets of the complete data set produce differing levels of correlation as listed in Table 5. The highest degree of correlation ($r^2 = 0.724$) was obtained for the Calumet Harbor data; as discussed earlier, the Calumet Harbor study was a more controlled field study. The lowest correlation, nearly zero, was obtained for the James River data. This low correlation is believed to arise because of the necessary use of only average swing velocities in the computation of the V_s/V_i and V_t/V_i parameters. Reported data for the study did not distinguish between varying swing speeds during the course of the dredging operations, and it is

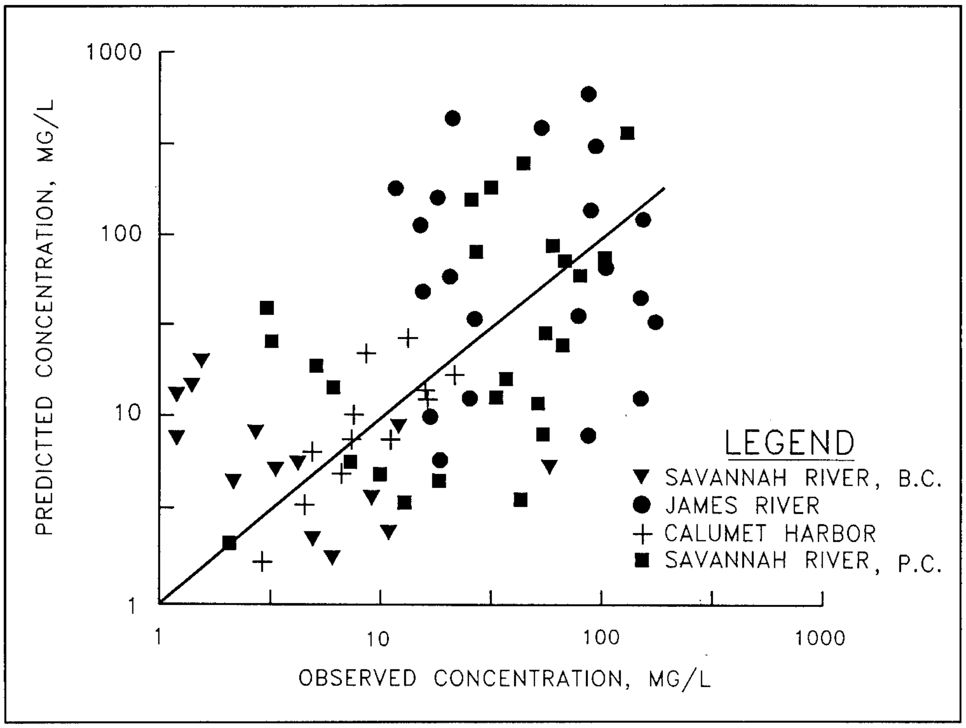

Figure 4. Sediment resuspension predictions for cutterhead dredge operating at full-cut burial

believed that there was, in fact, considerable variation. The overall correlation is dominated by the Savannah River data because of the relatively larger number of data items for the Savannah River study.

While there is far from perfect agreement between the predicted and observed data in Figure 4, there is a sufficiently reasonable comparison, it is believed, to conclude that the model provided by Equations 2, 3, and 4 as well as the full- and partial-cut models as described above provide a reasonable approach for estimating resuspended sediment concentrations produced by hydraulic cutterhead dredging. However, the equations should be applied cautiously to sites different from those used to develop the relationships. As more data become available in the future to further test this mathematical model, modifications to this exploratory model will certainly be necessary.

Dustpan Dredge

The dustpan dredge, used at the James River study site, was proposed as a means of reducing levels of resuspended sediments. This dredge, in the modified form used at the James River site, merely sucked up sediment loosened by the forward advance of the dredge, apparently creating a bulldozerlike motion to scoop and push sediment into the dredgehead where it would be sucked upward by the suction velocity. Winglets on each side of the dredgehead were supposed to restrict dispersal of sediment into surrounding waters.

Although limited data prevent a detailed evaluation of the dustpan dredgehead behavior, near field measurements (summarized in Appendix E) indicated resuspension was as high as or higher than that produced by the cutterhead dredge (Vann[1] 1983; Havis 1988; Raymond 1982; McLellan et al. 1989). Some of this may have been due to the apparently substantially larger forward velocities used with the dustpan dredge in comparison to the estimated swing velocities used for the cutterhead dredge (see Appendices E and F). In addition, if the effective area over which the intake suction velocity to the dredge occurs is approximated as a quadrant of a cylinder with a 2-ft radius and 28-ft length (Table 2), the effective surface area of the dredgehead is about 88 percent of that for the cutterhead dredge head used at the James River site. On the other hand, data presented by Vann[1] on dredge production during the testing period suggest that suction discharges of the dustpan dredge were approximately 60 percent of those for the cutterhead dredge. Thus the dustpan dredge may have had effective suction intake velocities of about $0.60/0.88 = 0.68 = 68$ percent of those of the cutterhead dredge. Since the cutterhead correlation suggests concentration levels are strongly inversely proportional to intake velocity, the larger concentrations observed during the dustpan dredge operation may be a result, at least in part, of the apparently smaller effective intake suction velocities for the dustpan dredgehead.

Matchbox Dredge

The matchbox dredge, studied at the Calumet Harbor site, was also proposed as a means to reduce release of resuspended sediments to the water column. The matchbox enshrouds the dredge suction intake with a box-type cover that allows sediment passage only through the open sides of the box. The necessary agitation and dislodgement of bottom sediment is accomplished by the mechanical and hydraulic forces as the dredgehead swings back and forth. There are no rotating cutter blades; thus presumably the resuspension of sediments by the dredge operation is insensitive to the direction of swing of the dredge ladder.

The concentration levels measured during three distinct sets of operating conditions for the matchbox dredge at Calumet Harbor (Appendices K and L) indicated that no measurable reductions in resuspended sediments in the immediate vicinity of the dredgehead were achieved compared to the conventional cutterhead dredge. In fact, for comparable operating conditions, sediment concentrations were sometimes greater than those for the cutterhead suction dredge. Previous researchers (Hayes, McLellan, and Truitt 1988; McLellan

[1] R. G. Vann. (undated). "James River, Virginia dredging demonstration in contaminated material (kepone), dustpan versus cutterhead," Report, U.S. Army Engineer District, Norfolk, Norfolk, VA.

et al. 1989) concluded that operator inexperience with this type of dredge, lack of adequate control in matchbox positioning near the channel bottom, and frequent clogging of the suction line affected the performance of the matchbox dredge.

The importance of proper positioning of the dredge near the channel bottom is emphasized by the results for the cutterhead suction dredge found above. While it is not immediately apparent how the absence of cutterhead rotation speed could be accounted for in describing resuspension with Equation 2, the presence of the ratio of swing speed to intake suction velocity raised to a 2.8 power suggests considerable sensitivity to the effective suction velocity in the water immediately surrounding the matchbox. Consequently, the effectiveness of the matchbox dredge may be very dependent upon the ability to precisely control the position of the matchbox near the bottom and achieve and maintain effective suction velocities conducive to small resuspension.

Hopper Dredges

One dredging study with a hopper dredge was conducted under the IOMT program (Table 1). Sediment resuspension was measured during both nonoverflow and overflow conditions in Grays Harbor, Washington. Because only one study has been accomplished for a hopper dredge, little quantitative information can be extrapolated as to the magnitude of sediment sources that might be generally produced by a hopper dredge. However, some observations are worthy of note.

Nonoverflow operating mode

Hopper dredges, because they are often used in strong current areas typical of many estuaries and outer harbors, use a hydraulic draghead on a dragarm suspended beneath the hopper vessel to cut and draw sediment upward into the ship's hoppers. The forward motion of the ship provides the primary cutting force while the hydraulic suction provides the necessary hydraulic lift and transport.

The actual suspended sediment concentrations aft of the moving hopper dredge studied in the IOMT program at Grays Harbor, Washington, are shown in Figure 5 (see Appendix N for concentration data listing). As an aid to viewing the data in Figure 5, approximating smooth curves have been drawn through each of the two data sets displayed in the figure. These data are vertical average concentrations within the estimated plume boundaries aft of the moving ship and have been averaged over longitudinal segments to provide a smooth plot of sediment concentration with distance as an aid for extrapolation. Strong tidal currents and ship movement prevented sampling in the immediate vicinity of the ship, and sediment concentrations at distances

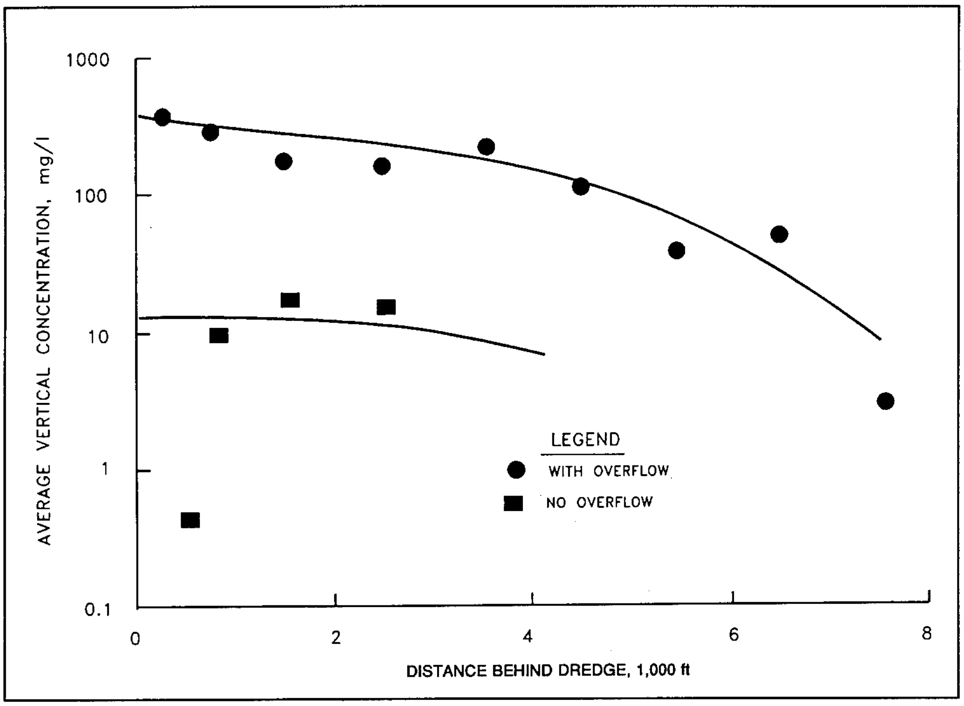

Figure 5. Resuspended sediment concentrations observed behind a hopper dredge operating in Grays Harbor, Washington

very close to the ship can only be estimated by extrapolation of data from greater distances.

Figure 5 shows that, as would be expected, the sediment concentration generally decreases with increasing distance from the dredge. The drop-off in sediment levels are evidenced in Figure 5 at a short distance downstream of the dredge in its nonoverflow operating mode. This is believed to be result of a combination of localized distortion of the sediment plume due to the ship's motion and associated large-scale turbulence and the difficulties in sampling along the axis of the plume in the regions nearer the dredge ship. If this lower value some 500 ft distant from the dredge is disregarded, the vertical average sediment concentration at zero distance from the dredge is estimated by extrapolation to be only about 13 mg/ℓ. However, this 13 mg/ℓ represents a vertical average. If the sediment throughout the vertical extent of the water column is presumed to be concentrated in a zone of height equal to the approximate size of the dredgehead (Table 2), the source concentration for the dredgehead becomes equal to approximately 146 mg/ℓ, as listed in Table 3.

Overflow operating mode

A distinctive feature of hopper dredges as sources of suspended sediment arises from the possibility that a hopper dredge normally provides two sources of sediment. Hopper dredges may be operated in either an overflow or non-overflow mode. In the nonoverflow mode, the material dredged from the channel bottom is loaded into the ship's hoppers only until the hoppers are full, after which the sediments are transported to their disposal site. Sediment levels above background levels are generated only by the disturbance of the moving dredge ship and its propellers, the draghead being towed by the dredge along the channel bottom, and increased velocities created by the waters being siphoned upward through the draghead. The source of suspended sediments is thus the agitation of sediments on the channel bottom by the dredge and dredge ship.

In the overflow mode of operation, the hoppers are filled beyond their point of capacity so that intentional spillage occurs. By pumping past the point of overflow, greater density is achieved in the sediment-laden waters retained in the hoppers; the greater density increases the effective capacity of the dredge with a resulting increase in the economy of the dredging operation. The supernatant overflow waters from the hoppers are discharged to the near-surface waters around the dredge ship, providing a second, near-surface source of suspended sediments from the dredging operation. As might be expected because of the high flow and concentration of sediments in the waters siphoned from the channel bottom and their short retention time in the hoppers, hopper overflow produces higher suspended sediment concentrations than the dredging action itself (McLellan et al. 1989).

The effects of these two different sources of sediment in a hopper dredging operation is illustrated by the data of Figure 5. It is apparent that vertical average sediment concentrations with overflow are approximately one to two orders of magnitude larger than without overflow in the regions near and at moderate distances downstream of the dredge. Generally, the average concentration, due to both dispersion of the sediment plume and settling of suspended particles, decreases with downstream position. The vertical average concentration level for the overflow mode of operation at a zero distance from the dredge is, by extrapolation, about 355 mg/ℓ.

Clamshell Dredges

Factors influencing resuspended sediment levels

A variety of factors in the use of clamshell dredges have been identified or suggested as contributing to the resuspension of sediment. Previous investigators (e.g., Hayes, McLellan, and Truitt 1988) have suggested that bucket impact, penetration, and withdrawal are major contributors to sediment resuspension. An additional source of sediment in the near field water column is the loss of sediment from the clamshell bucket as it rises through the water column, breaks the water surface, and is swung across to the point of bucket opening and dredged material release. In its upward movement, sediments overflow the top of the bucket, leak from the sides and bottom of the bucket, and are washed from the sides of the bucket. Based upon these factors, a general equation for sediment resuspension during clamshell dredging can be written as:

$$\begin{array}{c}\text{Total}\\\text{Resuspension}\end{array} = \begin{array}{c}\text{Resuspension by}\\\text{bucket impact,}\\\text{penetration, and withdrawal}\end{array} + \begin{array}{c}\text{Resuspension}\\\text{bucket leakage}\end{array} + \begin{array}{c}\text{Resuspension by}\\\text{bucket spillage}\end{array} + \begin{array}{c}\text{Resuspension by}\\\text{washing of sediment}\\\text{from bucket walls}\end{array}$$

While this equation includes the primary components of resuspension, these components are not easily modeled and are influenced considerably by other dredging characteristics. These characteristics are discussed below.

An important factor influencing total suspended sediment levels in the water column is the bucket cycle time, i.e., the time used to make a complete bucket lift, recovery swing, bucket opening and release, return swing, and bucket drop and return to the channel bottom. Other operational factors that may influence sediment generation include the amount of bottom sweeping or smoothing, if any, with the bucket by the bucket operator, and the number of passes used in removing the sediment at a particular location.

Bucket design and size, as well, can be expected to affect the amount of sediment generated. In the IOMT studies conducted to date, two different types of buckets have been used: (a) an open bucket (which is the common type of clamshell bucket), which allows some free drainage of water and sediment overflow as the bucket is hoisted upward, and (b) a closed bucket (sometimes referred as a watertight bucket). Various types of closed clamshell bucket designs have been previously described[1] (Arctic Laboratories et al. 1985; Herbich and Brahme 1991). The particular design of the closed or watertight clamshell buckets used in the IOMT studies have been described (Raymond 1984; Hayes, McLellan, and Truitt 1988; Hayes 1986b; Montgomery and Raymond 1984). Irrespective of the details of the design or the name given particular designs, these bucket designs are intended to minimize drainage from the bucket.

Sediment resuspension from the operation of a clamshell dredge may also arise from effects not directly associated with the bucket operation. These effects can include scow movement and associated tug operations, scow overflow, and direct release or "sidecasting" of dredged sediments (as was the case at the Lake City site).

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[1] U.S. Army Corps of Engineers, Office of Civil Works. (n.d.). "Dredging," Engineering School Manual, The Engineering Center, Fort Belvoir, Virginia.

Data analysis

Concentration levels very close to a clamshell dredge could not be measured in the field during actual dredging operations because of the danger posed by a lifting, swinging clamshell bucket. Consequently, in order to obtain a source concentration level for a particular clamshell bucket dredge, concentration levels at various radial distances from the dredge were extrapolated to deduce an approximate concentration at a zero radial position representing the idealized center of the dredge. Appendices P, Q, S, U, W, X, and Y tabulate concentration data for the various clamshell dredge operations.

Several factors had to be considered in developing the concentration data to make this extrapolation. Firstly, it was recognized that there was considerable apparent random scatter in the concentration data because of the inherent difficulties in making field measurements in the various dredge studies. Secondly, because the data at each dredging site were limited, it was necessary that as much of the available data as possible be used to estimate the source concentration at the idealized axis of clamshell bucket rise and fall. To address the first factor, concentration data were vertically averaged over the depth of the water column for each set of measurements at a particular time and location. To address the second concern, temporal variations arising from changing river current patterns were neglected and tidal effects were, as discussed below, only approximately accounted for; the amount of data was insufficient to segregate data by time or fraction of a tidal cycle.

In addition, the far field concentration levels used to make the source concentration estimates are not a function solely of radial distance, but rather depend on both radial distance and angular orientation relative to the dredge and current that may exist. However, because the data were limited, variation of concentration with angular position was difficult to distinguish in the field data at a level of detail considered necessary for making the desired extrapolation to a zero radial distance. Consequently, it was decided that only radial variation of concentration would be used in making the desired extrapolation. Two factors lessen the error that neglect of the angular orientation introduce: (a) the far field data used to make the extrapolation tended to be concentrated in regions along the streamwise axis (either upstream or downstream of the dredge) of the channel and sediment plume produced by the dredging; thus much of the data had approximately similar upstream or downstream angular orientations relative to the dredge; and (b) far field concentration patterns tended to become less dependent on angular orientation the smaller the radial distance from the dredge; thus in the vicinity of the dredge, far field concentration data assumed similar magnitudes for similar radial distances irrespective of angular orientation.

While temporal variations in currents and detailed tidal variations were not accounted for in the far field data analysis, it was clear from both the raw data and studies by previous investigators (Hayes, McLellan, and Truitt 1988; McLellan et al. 1989; Havis 1988) that both the typical river current and tides, when present, produced some asymmetry in the streamwise pattern of the far field concentration patterns. A river current would stretch the time-averaged concentration field surrounding the dredge in the direction of the current flow while compressing it in the opposing direction. Tidal variations, on the other hand, would cause a crudely cyclic variation in the concentration field that would evidence itself as two zones of high concentration when far field concentrations were averaged over time. Both these influences are clearly linked to the streamwise motion of a settling sediment particle and the horizontal distance in an upstream or downstream direction that a particle can move before it finally settles to the channel bottom.

Since the data were sufficient in number only for analysis on a time-averaged basis, the asymmetry in far field concentrations apparently introduced by river current and tides was accounted for by locating all data at adjusted radial positions somewhat different from their actual radial positions. Points upstream of the dredge in sites dominated by river current flow or, in the cases of strong tidal influences, points for measurements taken during the ebb tide had the streamwise component of their radial distances increased by a constant length, while points taken downstream of the dredge or on the flood tide had the streamwise component of their radial distances decreased by a similar amount. The actual adjustment varied with the site and was selected by trial and error to reduce the apparent scatter in vertical average concentration at various radial positions. Because data scatter could not be totally eliminated and reduction in scatter was evaluated subjectively, the selection of the adjustment distance was refined only to 10-ft increments. The magnitude of these adjustments (0 to 100 ft) is physically consistent with the time available for the horizontal movement that a falling sediment particle could undergo moving at current or tidal speeds typical of the various sites (Table 1).

Once the adjusted positions were determined for the concentration data for a particular clamshell dredge, the concentrations were plotted and fitted by eye with a smooth curve. Extrapolation of the curve to a zero radial distance yielded the clamshell dredge source concentration. These estimates of observed source concentrations are listed in Table 3. To reduce the effects of random error and angular orientation at larger radial distances in the plotting and curve fitting, the vertical average concentrations at different adjusted radial positions were averaged over radial zones before plotting. The width of the averaging zone depended on both the study site and the radial distance because of the differences in the number of data at different radial distances in each data set.

Figure 6 shows the radial variations of concentrations for the five different open clamshell bucket dredge studies (Table 1). For clarity, the concentrations have been normalized by the estimated source concentrations. Also for the sake of clarity, the closed clamshell data are not plotted in Figure 6; however, they behave in the same general manner as the open-bucket clamshell data shown. While there is certainly considerable scatter, the data shown in Figure 6 for each of the various sites do demonstrate a crude exponential decay of concentration with adjusted distance. Note that the approximate rate

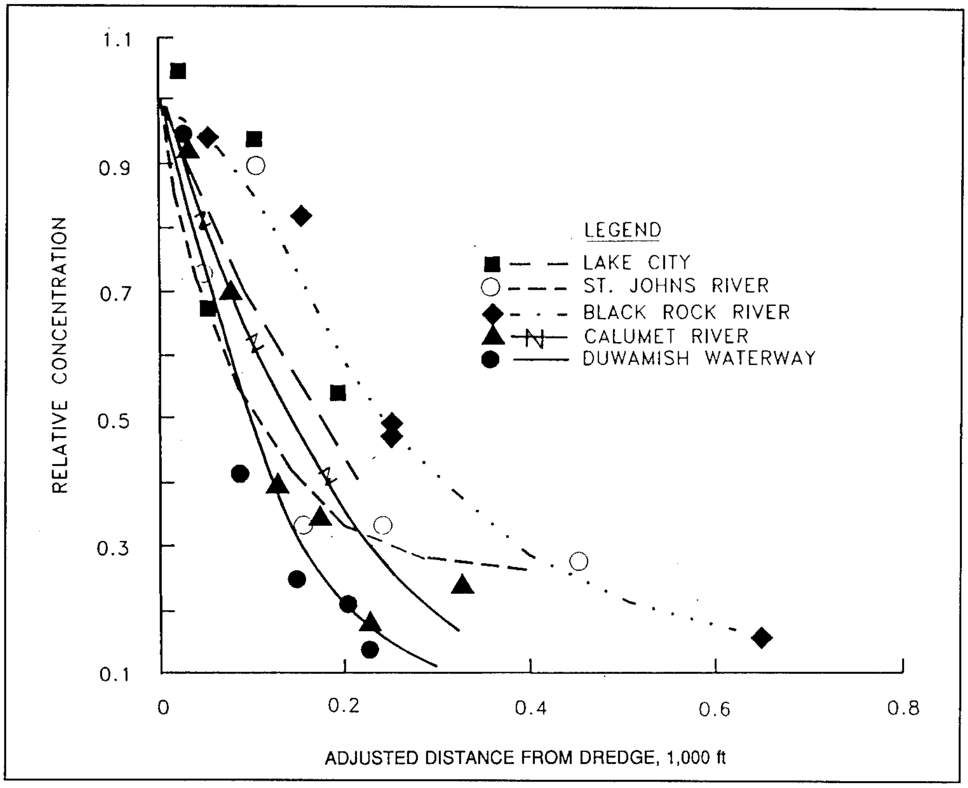

Figure 6. Relative resuspended sediment concentration versus distance for open-bucket clamshell dredges

of decay is different for each dredge. The decay is also different for each type of clamshell (i.e., open or closed). Such differences are to be expected because of differing sediment and flow characteristics.

Open clamshell source concentrations

The clamshell dredge source concentrations determined for the various dredges show differences from one another, as would be expected. These differences arise because of differences in sediment characteristics, clamshell bucket features, and bucket operation; their influence of these factors can be quantified through a combination of physical and dimensional reasoning. Less well-defined background flow conditions and local site peculiarities might also influence these source concentrations, but cannot be identified in the present analysis.

If dimensional reasoning is applied, one recognizes that the bucket size compared to the dredging depth should be important to the levels of sediment produced by a clamshell bucket: the bigger the bucket compared to the flow depth, the greater the sediment resuspension. Thus the dimensionless parameter B, where

$$B = b/h \tag{31}$$

in which b is a representative size of the clamshell bucket and h is the representative dredging depth (Tables 2 and 3), should influence the source concentration. The shape of a clamshell bucket is crudely square in the horizontal plane and one vertical plane and triangular in the third, orthogonal plane. Thus if the clamshell bucket volume is V_{cb}, then the characteristic size of the bucket can be defined by the relation

$$V_{cb} = b^3/2 \tag{32}$$

The time the clamshell resides in the water column should also affect sediment production; the longer the bucket is in the water column, the more time available for sediment loss from the bucket. The time in the water column should be closely proportional to the bucket cycle time for operation by an experienced dredge operator. Counterbalancing this effect, however, is that longer cycle time implies fewer bucket loads being removed in any definite period of time and thus less total sediment being removed over an extended period of time. Cycle times T for the open-bucket clamshell dredges are given in Table 2. This cycle time can be incorporated in a dimensionless parameter by defining a dimensionless cycle time S, where

$$S = v_s T/h \tag{33}$$

in which v_s is a representative settling velocity of the resuspended sediments.

A representative settling velocity v_s can be estimated from Stokes law using the median grain diameter d and specific gravity of the dredged sediments; values of v_s computed from Stokes' law are listed in Table 3 for all the dredge sites except Lake City and St. Johns River. No data on sediment size or settling characteristics were available for the Lake City site, and therefore no settling velocity was estimated. While median grain size data was also not available for the St. Johns River site, one set of settling column measurements for high concentrations of sediments was available. In lieu of other data, these settling column measurements were used to estimate a representative v_s for the St. Johns River site.

The settling column measurements for the St. Johns River site had been conducted at high concentrations of total suspended solids (20 percent); thus zone and compression settling were exhibited by the settling measurements. The interfacial velocity of the suspended sediment mass undergoing zone settling at the beginning of the settling column measurements was taken as an estimate of the particle setting velocity v_s. This interfacial velocity, determined from the slope of the curve of interfacial position versus time curve, was 5.143×10^{-3} ft/sec as listed in Table 3.

The available data allowed calculation of S and B for only three sets of data. Consequently a regression analysis on the two independent parameters S and B was not possible. However, the single parameter

$$S/B = (v_s T/h)/(b/h) = v_s T/b \tag{34}$$

which represents a normalized dimensionless setting velocity, correlated quite well with the source concentration C for the three sets of data. A regression analysis of the source concentration for the closed-bucket clamshell dredges at the St. John River, the Black Rock Harbor, and the Calumet River sites yielded the dimensionless equation

$$C/(\rho \times 10^{-6}) = 0.00235(B/S)^{3.033} = 0.00235\left[\frac{b}{v_s\ T}\right]^{3.033} \tag{35}$$

in which C is the open-bucket clamshell dredge source concentration. The linear correlation coefficient r^2 for the logarithmic equivalent form of Equation 35 is 0.979. Equation 36 can be closely approximated by

$$C/(\rho \times 10^{-6}) = 0.0023\left[\frac{b}{v_s\ T}\right]^{3} \tag{36}$$

A comparison of observed concentrations to those computed from Equation 36 is provided in Tables 3 and 6 and Figure 7.

Closed clamshell

The estimated source concentrations for the closed clamshell buckets are given in Table 3. For the St. Johns River, the source concentration is decreased in comparison to the open-bucket clamshell concentration, as might be expected. At the Lake City operation, however, the source concentration is higher for the closed-bucket clamshell operation. While the reason for this is not apparent, it may be because of the bucket size (the closed buckets were larger than the open buckets; (Table 2) and the bucket cycle time. While quantitative data were not reported on the cycle time T for the closed-bucket clamshell dredging operations, it is known that, because of the difficulty of forcing air out of the closed bucket, the cycle times for the closed-bucket

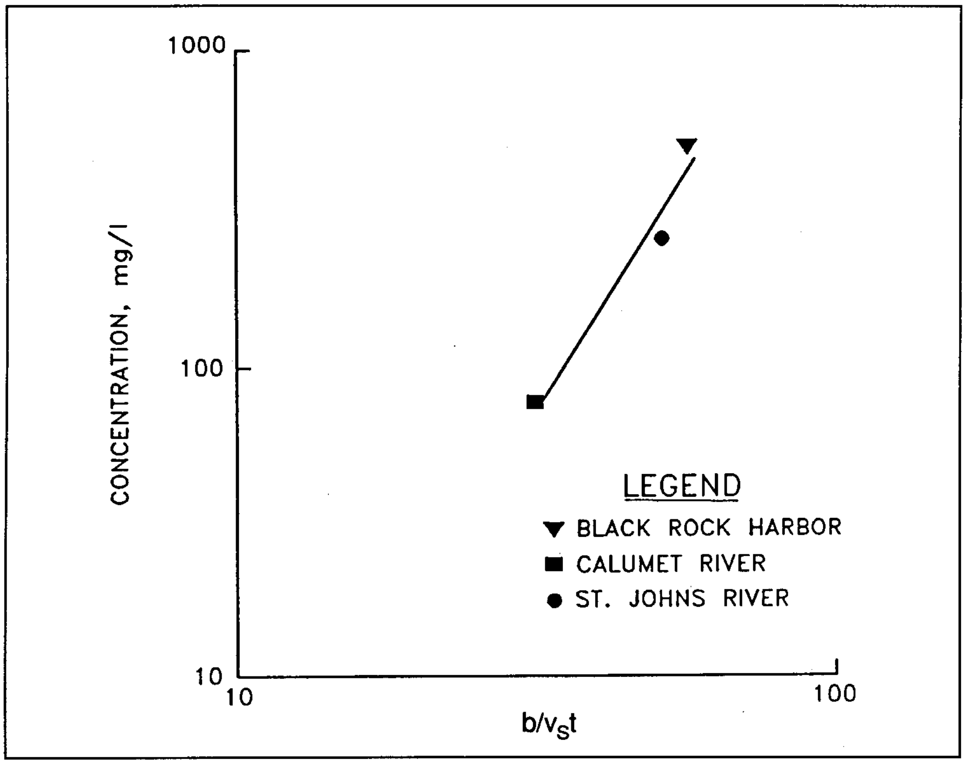

Figure 7. Open-bucket clamshell dredge correlation

clamshell dredging at both the Lake City and St. Johns River sites were at least as great as that for the open-bucket clamshells. It is also possible that the entrapped air in the bucket contributed to greater bucket impact on the bottom because the dredge operator may have attempted to overcome the air entrapment problems by trying to cause the bucket to drop more quickly than an open bucket. Sidecasting of the dredged sediment at the Lake City site may also account for the higher concentration levels observed with the closed-bucket operation.

Lack of data prevented an attempt to correlate closed-bucket clamshell resuspended sediment concentration with the S/B parameter of Equation 34; but the correlation of Equation 35 does suggest that cycle time, even for closed buckets, may be a crucial factor in the success of closed-bucket clamshell dredges in reducing resuspended sediment levels.

4 Suspended Sediment Source Strengths

Dredging operations are sources of resuspended sediment because of the hydraulic and mechanical actions of the dredge. Once introduced into the water column, resuspended sediments are advected and dispersed into the near and, ultimately, far field waters surrounding the dredge. Sediment resuspended as a consequence of the dredging can be described in terms of a resuspended sediment source and its associated source strength. Depending upon the type of dredge, different types of mathematical models can be used to describe this source and its strength.

Source strengths are mathematically inferred quantities and not directly measurable. The mathematical estimation of source strengths, even when incorporating field measurements on resuspended sediment concentrations, requires various assumptions. While these assumptions can be tested through application of mathematical models of resuspended sediment transport and deposition employing the estimated source strengths, the a priori descriptions of the resuspended sediment sources and their strengths provided below have not been verified and, therefore, must be considered as preliminary.

The estimation of resuspended sediment source strengths incorporates information about dredge characteristics and resuspended sediment concentrations in the immediate vicinity of the dredge or dredgehead. Of the several IOMT dredge studies described in the preceding chapters, only those for the cutterhead and clamshell dredges have sufficient information on which to formulate a source strength model. These studies, because they included more than one dredging operation for each of the dredge types, provide not only correlation of resuspended sediment concentration, but also demonstrate the specific influences of sediment properties, dredge characteristics, and dredge operating parameters. The remaining studies on the dustpan, matchbox, and hopper dredges do not provide such detail. Conceptual models for these latter type of dredges could be envisioned, but would be highly speculative and of limited utility since source concentrations could not incorporate dependencies on dredge characteristics and sediment properties.

Features of Source Model Structure

The strength of the resuspended sediment source, designated as R, is the temporal rate at which mass (or weight) of sediment is introduced into the near field waters surrounding a dredge as a consequence of a dredging activity. This source strength, as used here, describes the resuspended sediment in excess of background levels; it is assumed that the source strength is independent of such background suspended sediment levels.

The introduction of sediment into the water immediately surrounding the dredge represents a mass (or weight) flux of resuspended sediment originating from the source. This flux can be expressed in terms of the product of representative concentrations and velocities distributed over a source surface or boundary. Calculation of the resuspended sediment source strength from actual dredging data therefore requires a description of (a) the geometry of the source and source boundary surfaces, (b) the fluid velocity structure or fluid movement at the source boundaries, and (c) the resuspended sediment concentrations at the source boundaries.

Source geometry

For mathematical modeling and purposes of analytical analyses, a source may be conceived as being concentrated at a point, along a line, or over a surface. The choice of the geometric shape for a mathematically idealized source is based upon the physical system being described and mathematical convenience. Practical definition of source geometry must recognize the type of data (field data in the present study) from which velocities and sediment concentrations in and around the source are estimated. Because there is a practical limit upon how small a region around a particular dredge can be sampled, it is necessary to define the source strength using an approximating geometry for the source. Different types of source geometries of finite size, i.e., different source volumes, are therefore used in describing the source strengths for various types of dredges.

Source concentration

Correlations for resuspended sediment concentrations in the immediate vicinity of a dredge or dredgehead have been provided in Chapter 3 of this report for both cutterhead and clamshell dredges. These concentration correlations are functions of dredge characteristics, dredge operation, and sediment characteristics. The concentrations predicted by these correlations are the concentrations presumed to exist on the surface of the conceptualized source volume. Source volumes are defined so as to be consistent with the geometric assumptions made in deduction of these concentrations from field studies. For the cutterhead dredge, the concentrations are those immediately surrounding the cutterhead itself; for the clamshell dredge, these concentrations are the vertical average concentrations about the axis of the vertical motion of the clamshell bucket.

Velocity structure

The source models given below use a velocity that represents a fluid motion creating a transporting flux of resuspended sediment away from the surface of the source volume. This velocity, in general, is assumed to be the net result of the particular velocities induced by the operation and motion of the dredge bucket or dredgehead. Velocities induced by tides, currents, or similar external fluid motions are not directly included because the velocity field in the vicinity of the dredge is modified and disrupted by the dredge operation. The fluid velocity in the near field about the dredge is a localized velocity field defined in large measure by the configuration of the dredge and dredgehead or bucket motion.

Model coefficients

Mathematical models of hydraulically related phenomena, such as sediment resuspension, often incorporate unknown coefficients to account for effects or parameters not readily quantified. Ultimate use of such models requires a determination, usually by physical experimentation or field measurements, of those coefficients. The models formulated here limit the use of such coefficients for the following reason: the intended use of the present source strength models is to provide a priori estimates of resuspended sediment source strengths that can be initially used for numerical modeling of the resuspended sediment transport process, and, in addition, assist in identifying parameter groupings that characterize the effects of source strengths. A priori estimation cannot incorporate unknown coefficients; thus models must be formulated which, although possibly crude, incorporate parameters that are generally known or can be reasonably estimated.

Cutterhead Dredge

Source volume geometry

The resuspended sediment source volume geometry for a cutterhead suction dredge is taken as the dredgehead, approximated in its shape by a semi-ellipsoid with its minor axis and major axis equal to the maximum radius and length, respectively, of the cutterhead. This geometry is the same as that previously used to define the inwardly directed cutterhead suction intake velocity V_i and characteristic cutterhead size L.

Because of the washoff of sediment from the cutterhead, there develops a zone of resuspended sediment concentration C about the cutterhead, where the concentration C is given by the model of Equations 1 through 3. As a consequence, the swinging motion of the cutterhead creates a moving resuspended sediment source volume of magnitude V_{ch} with a volume average concentration C. While the calculation of the concentration in this zone is based upon the semi-ellipsoid source volume, the actual volume over which the concentration C may typically exist may occupy a volume larger than V_{ch}. The vertical extent of this volume is $(1 + k_{ch})D_{ch}$, while the length of this volume in the direction of the axis of the cutterhead is $(1 + k'_{ch})L_{ch}$; both k_{ch} and $k'_{ch} \leq 1.5$, where k_{ch} and k'_{ch} are size factors for the diameter and length of the cutterhead, respectively. In shallow waters where $(1 + k_{ch})\, D_{ch}$ exceeds the depth of the water, the vertical extent of the zone where the concentration is C would be limited by the depth of water.

Velocity structure

The motion of the cutterhead blades relative to overlying waters and eddy-induced motions behind the swinging cutterhead ladder wash sediment from the cutterhead blades and disperse it into the overlying waters. The rate at which the washing proceeds and the rate at which water is sweeping by the cutterhead due to the combined motion of the swinging ladder arm and the cutterhead blades is characterized by the net velocity V_t of the cutterhead blades near the top of the cutterhead rotation. Thus, similar to the deductions of Chapter 3,

$$V_t = V_c + V_s \qquad \textit{for overcutting} \tag{37}$$

$$V_t = V_c - V_s \qquad \textit{for undercutting} \tag{38}$$

While V_t is based upon the vector summation of velocities V_c and V_s at the top of the cutterhead, this velocity is viewed as a representative velocity at which resuspended sediment is generally introduced into the water immediately surrounding the cutterhead because of the combined motion of the cutterhead ladder arm and the rotating cutterhead. That is, for evaluation of source strength, V_t is a representative washoff speed tending to convey resuspended sediment away from the trailing side of the cutterhead.

Source strength

At any moment during the period of swing of the cutterhead ladder arm, the total mass flux of resuspended sediment emanating from the semi-ellipsoidal source volume is the result of the resuspended sediment passing across a surface in the plane orthogonal to the motion of the cutterhead ladder arm, i.e., across a plane of height $(1 + k_{ch})D_{ch}$ by length $(1 + k'_{ch})L_{ch}$. Thus the source strength is

$$R = C\ V_t[1 + k_{ch}]D_{ch}[1 + k'_{ch}]L_{ch} \tag{39}$$

in which C is given by Equations 1 through 3. If C is in mg/ℓ, V_t in m/sec, and L_{ch} and D_{ch} in m units, then R will be g/sec units. If C is in mg/ℓ units while V_t is in ft/sec and L_{ch} and D_{ch} are in f units, then R will be in (mg/ℓ) (ft^3/sec) units, where 1 (mg/ℓ)(ft^3/sec) = 0.0283 g/sec.

Source strengths as computed from Equation 39 for some representative parameter values at the Savannah River, James River, and Calumet Harbor IOMT dredge sites are listed in Table 7.

Clamshell Dredge

Defining the resuspended source strength for the clamshell dredge requires relating resuspended concentration conditions to characteristics of the clamshell bucket and its operation. Resuspended sediment concentrations are related to these characteristics by Equation 36 for the open-bucket clamshell dredge. A corresponding equation was not developed for the closed-bucket clamshell dredge. Consequently, no attempt is made to identify the source strength for a closed-bucket clamshell dredge. However, should such a correlation be identified, its use to define dredge source strength would likely track that for the open clamshell bucket dredge.

Source geometry

The source geometry for a clamshell dredge is idealized as a cylindrical column of vertical height equal to the depth of water h in which the clamshell dredge is operating. Because a clamshell bucket is approximately square in the horizontal plane with area b^2 and, as given by Equation 32, has an approximate volume of $b^3/2$, the effective cross-sectional area of the cylinder in the horizontal plane is taken as b^2 while its perimeter is taken as $4b$, (Table 3). Note that the ratio of this effective cross-sectional area to perimeter is $b/4$, just as it would be for a circular cylinder. This geometry is only approximate since turbulent mixing will cause the resuspended sediment to occupy a volume larger than the idealized cylindrical source volume. The increased volume can be approximately accounted for by increasing the effective size of the bucket; this bucket size modification can be done after the resuspended sediment source strength for the actual bucket size is determined. Thus the development to follow first assumes that the actual bucket size is used to describe the source volume and resulting source strength. A postanalysis adjustment to the computed source strength is then made to account for the increase in effective bucket size due to turbulent mixing.

Because of the way it was derived from field data, the concentration given by the correlation of Equation 36 is the temporal vertical average concentration in the idealized center of the clamshell dredge; by assumption, this center corresponds to the vertical axis of the cylindrical source volume about the axis of rise and fall of the clamshell bucket. It is recognized that as dredging progresses this axis may slowly move, but such movement is not specifically accounted for in the following development.

Fluid and suspended sediment motions

The rising and falling motion of the clamshell bucket produces a pumping type of motion, periodically forcing sediment-laden waters from the source volume. This motion is responsible for the introduction of resuspended sediment into the near field about the dredge. Effects of currents, if present, would be accounted for in the far field modeling, which might use the source strength model to be developed in the following.

The start of a typical cycle of bucket motion can be conveniently taken as the time of bottom impact of a falling bucket; at this moment, time $t = 0$. The fluid motions resulting in the ejection of sediment outward across the cylindrical source volume surface can then be described in terms of the sequence of events over the time of a full cycle of bucket operation from $t = 0$ to $t = T$, where T can be decomposed into the following fractions of total cycle time:

f_u = fraction of the cycle time over which the bucket is rising in the water column

f_d = fraction of the cycle time over which the bucket is falling in the water column

f_b = fraction of the cycle time for which the bucket rests on or is dragged along the bottom

f_o = fraction of the cycle time for which the bucket is completely out of the water

where

$$f_u + f_d + f_b + f_o = 1 \tag{40}$$

Note that as a practical matter, f_b is usually nearly 0.

At time $t = 0$, bottom sediment is loosened by the bucket impact and the bucket claws gather sediments into the bucket; at time $t = f_bT$, the bucket begins to move upward. It is assumed that loosened materials not taken into the bucket remain near the bottom and do not significantly contribute to the sediment that passes across the surface of the source volume. The source of sediments moving across the surface of the source volume are assumed to be primarily those draining from the bucket because of bucket leakage, washoff, or overflow as the bucket is lifted upward at an assumed constant velocity v_u, where

$$v_u = h/(f_u \; T) \tag{41}$$

As the bucket is lifted upward, sediments draining from the bucket fill the water column below the bucket. Because of the induced turbulence, the resuspended sediments are uniformly mixed in the water column below the bucket. When the bucket finally breaks free of the water surface at time $t = (f_u + f_b)T$, the entire cylindrical source volume is filled with resuspended sediment with an average concentration C_u. In this idealized view, the waters above the bucket remain free of resuspended sediments. The mass rate r of sediment drainage from the bucket is assumed to be constant, so that at any time t the mass m_u of sediments in the water column below the bucket is given by

$$m_u = r \; (t - f_b T) \tag{42}$$

The volume over which this mass of sediment is distributed is given by $v_u \; (t = f_b T) \; b^2$, from which it follows that the volume average concentration, say c_u, the concentration below the bucket during the rise, at any time during the period of bucket lift is

$$c_u = \frac{m_u}{\left[v_u \; b^2 \left(t - f_b T\right)\right]} \tag{43}$$

But since

$$r = \frac{m_u}{(t - f_b T)} \tag{44}$$

from Equation 42,

$$c_u = \frac{r}{v_u\, b^2} \tag{45}$$

Thus the concentration c_u throughout the period of lift is a constant and therefore

$$C_U = c_u \tag{46}$$

This conceptual view of the accumulation of suspended sediments in the source volume neglects the return of sediments from surrounding waters because of the inward motion of fluid due to the lifting of the bucket. The neglect of this sediment recapture is considered reasonable because of the advection and dispersal of sediments away from the bucket during the next period of bucket fall.

Once the bucket begins to fall, at an assumed constant rate of v_d, where

$$v_d = h/(f_d T) \tag{47}$$

all the suspended sediment beneath the bucket in the source volume at the time $t = (f_b + f_u + f_o)T$ must be ejected from the source volume by the end of the cycle at $t = T$ when the bucket reaches the bottom if it is assumed the water directly above the bucket remains essentially devoid of suspended sediment. Bucket sediment washoff during the bucket fall is neglected; its magnitude is considered small in comparison to the sediments accumulated in the water column during the bucket rise. Because both the fall velocity of the sediments and the time $f_o T$ can be expected to be small, the concentration in the source volume at $t = (f_b + f_u + f_o)\,T$ is set equal to C_U, the concentration at $t = (f_b + f_u)T$. Consequently, the total suspended sediment mass ejected over the period of fall must be $C_U b^2 h$.

However, the sediment ejected is the strength of the source. Therefore the average source strength R over the complete cycle of the bucket motion must be

$$R = C_U\, b^2\, h/T \tag{48}$$

Thus to determine the source strength R, the concentration C_U must be determined.

Source concentration

The concentration given by the correlation of Equation 36 is the temporal vertical average concentration for the source; it defines this average concentration C in terms of bucket size and operation. Thus to determine the strength R given in Equation 48 in terms of bucket size and operation, it is necessary to express C_U in terms of the temporal vertical average concentration C. This is accomplished through the steps outlined in the following paragraphs.

From $t = (f_b + f_u + f_o)\,T$ to $t = T$, the bucket is falling at an assumed constant velocity v_d (Equation 47) forcing sediment-laden water outward and away from the source volume by flow across the source volume surface with a spatial average radial velocity v_r, where by continuity

$$v_r 4b\{h - v_d[t - (f_b + f_u + f_o)T]\} = v_d\, b^2 \tag{49}$$

(Note that the product of the radial velocity and surface area of the source volume is a constant because v_d is an assumed constant.) If it is assumed that the resuspended sediment concentration, say c_d, at any time during the bucket fall varies linearly from C_U at time $t = (f_b + f_u + f_o)T$ to some value C_T at time t = T, then it can be demonstrated, as follows, that

$$C_T = C_U \tag{50}$$

To demonstrate the equality of Equation 50, consider the following: if it is assumed all suspended sediment must be forced out of the source volume by the time the bucket reaches the bottom, the total sediment mass ejected during the duration of time $f_d T$ must be $C_U b^2 h$. Because of the assumed linear variation of concentration, the concentration at any moment is

$$c_d = (1 - f')C_U + f'C_T \tag{51a}$$

where

$$f' = [(t/T) - (f_b + f_u + f_o)]/f_d = [(t/T) - (1 - f_d)]/f_d \tag{51b}$$

That is, $f' = 0$ when $c_d = C_U$ and $f' = 1$ when $c_d + C_T$. The instantaneous total mass flux, M_d, across the source volume surface becomes, in view of Equation 47

$$M_d = c_d \, v_d \, b^2 \tag{52}$$

Integrating Equation 52 over the period of bucket fall yields the total sediment mass, which must also equal the total sediment mass at the instant the bucket begins its downward motion; thus

$$\int_{f_b + f_u + f_o}^{1} T \, M_d \, d(t/T) = \int_{f_b + f_u + f_o}^{1} T \, c_d \, v_d \, b^2 \, d(t/T) = C_U \, b^2 \, h \tag{53}$$

Using c_d from Equation 51 in the integration of the second integral of Equation 53 results in, after simplification,

$$(1/2)(C_U + C_T) \, f_d \, T \, v_d \, b^2 = C_U \, b^2 \, h \tag{54}$$

or, substituting v_d from Equation 47,

$$C_t = C_U$$

which demonstrates the equality of Equation 50. The equality exists because of the assumption that c_d varies linearly during the period of bucket fall. Thus, the concentration is constant during the period of bucket fall.

Because of the equality demonstrated by Equation 50, the concentration conditions beneath the bucket can now be readily averaged over the vertical height of the source volume and the duration of the cycle time to yield the temporal vertical average concentration C_a of the resuspended sediment source. Since the bucket rises and falls at a constant rate and the resuspended sediment is assumed to be only below the bucket, this average is computed to be

$$C_a = [(1/2) \, f_u + f_o + (1/2) \, f_d] C_U \tag{55a}$$

or

$$C_U = \frac{2C_a}{(f_u + 2 \, f_o + f_d)} \tag{55b}$$

Consequently the source strength becomes, using Equation 48

$$R = b^2 \,(h/T) \frac{2C_a}{(f_u + 2\,f_o + f_d)} \tag{56}$$

The average concentration C_a computed in Equation 55a is based upon a source volume with cross-sectional area b^2, but, as previously noted, the resuspended sediments, because of turbulent mixing, are not restricted to the volume directly beneath the bucket. Because of mixing, the effective cross-sectional area of the source volume can be described as $(1 + k_{cb})b^2$, where k_{cb}, the size factor for the diameter of the clamshell bucket, is an empirical or experimentally estimated factor. Observations by Bohlen (1978) suggest that $1 + k_{cb}$ might on the order of 2 or 3. Because of this increased volume size, the average concentration C that would be actually observed in the source volume region would be less than C_a because the mass assumed to be in the area b^2 would be in fact spread over the area $(1 + k_{cb})b^2$. Thus, Equation 56 is modified to

$$R = 2b^2(h/T)(1 + k_{cb}) \frac{C}{(f_u + 2\,f_o + f_d)} \tag{57}$$

The concentration of C of Equation 57 is also the concentration of Equation 36, the observed source concentration in the immediate vicinity of the bucket. Thus using the correlation of Equation 36,

$$R/(\rho \times 10^{-6}) = 0.0023b^2(1 + k_{cb})(b/v_sT)^3 \left[\frac{2(h/T)(1 + k_{cb})}{(f_u + 2\,f_o + f_d)} \right] \tag{58}$$

Some source strengths for representative values of clamshell dredge parameters as computed from Equation 37 are listed in Table 6. The parameters selected correspond to the open clamshell dredges studied in the IOMT program whose characteristics have been listed in Table 3.

5 Summary

Sediment resuspension by dredging is of concern because of the potential release of contaminants from bottom sediments, alteration of the physical and chemical characteristics of overlying waters, and subsequent resettling of sediments in environmentally sensitive areas. Bottom sediments introduced into overlying waters in the immediate vicinity of an operating dredge are advected and dispersed about the area of dredging by dredging-induced fluid motions and ambient currents and tides. This study focuses upon the near field area immediately surrounding a dredge and only incidentally considers points in the more distant far field. Because of the complexity of dredging-induced resuspension, both field measurements and mathematical modeling are used to describe the resuspension and subsequent transport processes.

Field measurements on dredging-induced resuspended sediment concentrations at nine inland and coastal dredging sites across the United States have been previously made, over the period of 1982 to 1985, under the Improvement of Operation and Maintenance (IOMT) Research Program. The dredge types studied were the cutterhead suction dredge at the Calumet Harbor, James River, and Savannah River sites, the matchbox dredge at the Calumet Harbor site, the dustpan dredge at the James River site, the hopper dredge with and without overflow at the Grays Harbor site, the open-bucket clamshell dredge at the Black Rock Harbor, Calumet River, Duwamish Waterway, Lake City, and St. Johns River sites, and the closed-bucket clamshell dredge at the Lake City and St. Johns River sites. These data were examined in this study for two purposes: (a) estimation of the dredging-induced resuspended sediment concentrations at or very near the actual point of dredging as a function of the dredge and dredge operating characteristics and sediment properties and (b) development of mathematical models providing a priori estimates of the temporal rate of sediment mass generation by the dredge at the point of dredging. The resulting correlations are based upon field data limited by both quality and availability. Further, the mathematical models proposed for sediment generation rates are based upon a combination of the concentration correlations and physical reasoning and assumptions; consequently, these models must be viewed as rudimentary and unverified.

Resuspended sediment concentrations at various points in the flow field about a dredge were obtained from field measurements by subtracting estimated background concentrations (i.e., concentrations that would exist in the absence of dredging) from measured total suspended sediment concentrations. These net concentrations were used to estimate the resuspension levels at the idealized dredging point. In the case of the cutterhead, dustpan, and matchbox dredges, data collected in very close proximity to the dredgehead could be used to make this estimation. The operational features of the remaining dredge types prevented field measurement extremely close to the dredging device (either a draghead or dredge bucket). For these dredges, concentration data at various distances from the dredge were averaged or smoothed in space and time to permit extrapolation of concentrations inward to the idealized dredging point.

Sediment resuspension by cutterhead suction dredges at a particular site is strongly dependent upon the swing speed of the ladder arm supporting the cutterhead, the rotational speed of the cutterhead blades, and the intake suction velocity at the cutterhead. Some directional sensitivity to ladder arm swing direction apparently exists and is reflected in higher resuspension levels in overcutting modes (when the cutterhead blades at their highest point are turning in the same direction as the ladder swing) versus those in an undercutting operating mode (when the cutterhead blades at their highest point are turning in the opposite direction to the ladder swing). As evidenced by resuspension levels at different study sites ranging, collectively, from approximately 2 to 300 mg/ℓ, resuspension is also influenced by the typical sediment particle size distribution of the sediments being dredged. These various parameters can be combined in dimensionless groups and correlated with resuspension concentrations observed close to the dredgehead. Cutterhead burial also affects the amount of resuspension. Both partial-cut and buried-cut dredging increase resuspension above that for full-cut dredging (when the top of the dredge cutterhead is at the mudline); a preliminary quantification of these impacts is provided.

The matchbox and dustpan dredges were proposed for field study in the IOMT program because of their reported potential to reduce resuspension levels in comparison to those produced by a cutterhead suction dredge. While matchbox and dustpan dredges rely upon fluid suction to collect bottom sediments as do the cutterhead suction dredges, neither the matchbox nor dustpan dredge employs rotating cutterhead blades to loosen and dislodge bottom sediments. However, difficulties in collecting data and inexperience in the actual operation of these two dredge types prevented a comprehensive quantitative evaluation of resuspension by these dredges at the study sites. The limited data are inconclusive as to the general effectiveness of these two dredge types in reducing resuspension in comparison to the resuspension produced by a cutterhead suction dredge.

The one hopper dredge studied in the IOMT program provided insight into the increases in resuspended sediment concentrations as a consequence of intentional overflow of the dredge hoppers. The estimated concentration level in the immediate vicinity of the dredgehead on the dragarm beneath the dredge was approximately 146 mg/ℓ which, when averaged over the vertical depth of overlying waters, yielded a value of about 13 mg/ℓ. When overflow from the dredge hoppers was allowed, the depth-averaged concentration increased about thirtyfold to 355 mg/ℓ.

Clamshell dredges use both closed- (i.e., watertight) and traditional open-bucket designs. The closed-bucket designs, two of which were studied at IOMT sites, seek to limit the overflow and leakage from the bucket as it is drawn upward in the water column and thereby lessen the introduction of sediment into the water column in comparison to the open-bucket clamshell, from which overflow and leakage are significant. However, difficulties in the operation and data collection for the closed-bucket dredges in the IOMT studies prevented a comprehensive evaluation of the closed-bucket designs. Estimated depth-averaged concentrations along the axis of bucket entry and withdrawal were in the 50- to 500-mg/ℓ range for both open and closed buckets. In the examination of open-bucket resuspension, certain parameters were concluded as being important in the characterization of the resuspension. Values for these parameters were not available for the closed buckets. Therefore, evaluation of impacts of clamshell dredge operation on resuspension focused upon the traditional open-bucket design.

Physical reasoning about the nature of the operation of an open-bucket clamshell dredge suggests that, among other factors, the bucket cycle time, bucket size, and sediment fall velocity are particularly important to the resuspension of sediment in the zone surrounding the axis of bucket rise and fall. A dimensionless grouping of these parameters could effectively correlate depth-averaged concentration data from the sites for which the values of these parameters were available. The correlation, furthermore, demonstrates a physically realistic dependence upon settling velocity, bucket size, and cycle time.

The amount of dredging-induced resuspended sediment can be described in terms of the temporal rate of sediment mass resuspended at the idealized point of the dredging. This sediment source is characterized in terms of a source volume of a particular geometry and source strength. Using a combination of physical reasoning, various reasonable but approximating assumptions, and the concentration correlations developed for the cutterhead and open clamshell dredges, resuspended sediment source models were formulated for both the cutterhead dredge and the open-bucket clamshell dredge. For the cutterhead dredge, the source geometry is an semi-ellipsoidal volume surrounding the cutterhead. For full-cut dredging, sediment is carried through the surface of this volume primarily by the net washoff of sediment from cutterhead blades produced by the combined motion of cutterhead blade rotation and cutterhead ladder swing. For the clamshell dredge, the source is a cylinder about the axis of bucket rise and fall. Sediment draining from a rising bucket accumulates in the cylinder and is then forced outward from the cylinder due to the downward motion of the falling bucket as it begins another cycle. The source strength is obtained by averaging the effects of this pumping-like motion over a typical cycle of the bucket operation.

The study provides an overview of resuspended sediment concentrations in the immediate, localized near field zone of certain types of dredges studied in the IOMT program. In the case of cutterhead dredges and open-bucket clamshell dredges, these concentrations have also been quantitatively correlated with parameters characteristic of the dredge, its operation, and the site of its operation. The models proposed for estimating resuspended sediment generation at the dredge provide insight into the impact of dredge and dredge operation on sediment resuspension. They also provide a starting point for a more thorough analytical evaluation of the entire resuspension, transport, and deposition process.

Well-defined and controlled field studies are needed to refine and improve the correlations identified and mathematical models proposed in this study and evaluate the effects of different types of dredges other than the cutterhead dredge and open-bucket clamshell dredge. Focused laboratory studies on the phenomena of cutterhead blade washoff and mixing around rising and falling cylinders may provide additional insight into the resuspension by, respectively, the cutterhead dredge and the clamshell dredge. The resuspended sediment source models developed in this study need to be critically examined through analytical or numerical modeling of the entire flow field around a dredge and comparison of the modeling results to field data measured at the IOMT sites either previously studied or that might be studied in the future.

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Table 1
Summary of IOMT Field Studies

Study Site Field Sampling Period (Identification Symbol)	Dredge Type	Site Environment (Salinity Range)	Dredged Sediment Characteristics: ( ) = USCS Designation; d = Median Grain Diameter, mm; SG = Specific Gravity	Typical Current Range fps	Representative Background Concentrations, mg/ℓ, Near Surface Near Bottom
Calumet Harbor 10/24/85-10/26/85 10/21/85-10/22/85 (CH)	Cutterhead Matchbox	Freshwater Lake	Silty loam (ML) d = 0.043 mm; SG = 2.71	0.0 - 0.2	1 - 4 1 - 4
James River 4/27/82-4/29/82 6/7/82-6/14/82 (JR)	Dustpan Cutterhead	Estuary (< 1 ppt)	Very soft silty clay (mostly CH, some MH & SM) d = 0.0156 mm; SG = 2.73)	0.3 - 2.6	42 - 43 86 - 90
Savannah River 7/7/83 - 7/26/83 (SR)	Cutterhead	Estuary[1]	Soft, organic clay/silt mixture (OL, OH) d = 0.023;[2] SG[1]	0.1 - 2.6	17 67
Grays Harbor 11/2/83 - 11/10/83 (GH)	Hopper with & without overflow	Estuary (1 - 20 ppt)	Sandy silt (ML) d = 0.033 mm; SG = 2.72	0.4 - 2.5	12 - 28 54 - 60
Black Rock Harbor 5/2/83 - 11/10/83 (BR)	Open clamshell	Estuary (10 - 21 ppt)	Sandy organic clay (OH & CH) d = 0.043 mm;[3] SG = 2.39	0.2 - 0.8	45 69

(Continued)

[1] Unavailable data.
[2] Based upon regional data presented by Herbich and Brahme (1991) for Savannah Harbor Area.
[3] Average of three extrapolated grain size curves.

Table 1 (Concluded)

Study Site Field Sampling Period (Identification Symbol)	Dredge Type	Site Environment (Salinity Range)	Dredged Sediment Characteristics: ( ) = USCS Designation; d = Median Grain Diameter, mm; SG = Specific Gravity	Typical Current Range fps	Representative Background Concentrations, mg/ℓ, Near Surface Near Bottom
Calumet River 8/20/85 - 8/23/85 (CH)	Open clamshell	Freshwater lake	Silty organic clay/silt mixture (OL) d = 0.043 mm;[4] SG = 2.71[4]	< 0.2	9 - 12 10 - 18
Duwamish Waterway 3/26/84 (DW)	Open clamshell	Estuary (3 - 18 ppt)	Organic silt & clay with sand (MH, ML, CH, OH) d = 0.012 mm; SG = 2.62	0.0 - 1.1	11 26
Lake City 4/11/84-4/12/84 4/13/84-4/16/84 (LC)	Closed clamshell Open clamshell	Freshwater lake	Soft, organic clay/silt mixture (OL, OH) d[1]; SG[1]	0.0 - 2.0	2 - 5 10 - 27
St. Johns River 2/9/82, 2/11/82, 2/10/82 (SJ)	Closed clamshell Open clamshell	Estuary[1]	Silt (MH) SG = 2.4 d[1]	0.0 - 0.2	47 72

[4] Assumed to be same as Calumet Harbor.

Table 2
Summary of Dredge Characteristics

Site (Vessel Name)	Dredge Type (Suction Pipe Diameter, in.)	Cutterhead or Bucket Size	Clamshell Cycle Time or Operation Mode	Representative Maximum Dredging Depth, ft	Average Height of Sampling Tubes Above Center of Cutterhead, ft
Calumet Harbor (*Dubuque*)	Cutterhead (14)	3 ft diam x 2.5 ft long	Full cut	31	2.2
	Matchbox (14)	6 ft long x 7.5 ft max width x 2.67 ft high	Hydraulic suction	31	
James River (*Essex*)	Cutterhead (21)	5 ft diam x 5 ft - 1 in. long	Full cut	25	8.6
	Dustpan (21)	28 ft wide x 2 ft high inlet zone with side winglets	Bulldozer action without hydraulic jets	25	
Savannah River (*Clinton*)	Cutterhead (20)	6 ft diam x 5 ft long	Buried cut & partial cut	50	4.5
Grays Harbor (*Essayons*)	Hopper dredge with trailing arm suction	6,000-cu yd hopper with below-waterline overflow ports & 28-in. diam x 3.66-ft-long dragarm	10-15 min to reach overflow 10-15 min of overflow	27	
Black Rock Harbor (J.W. Lyons)	Open clamshell	10-cu yd bucket	40 sec Sweeping used	20	

(Continued)

Table 2 (Concluded)

Site (Vessel Name)	Dredge Type (Suction Pipe Diameter, in.)	Cutterhead or Bucket Size	Clamshell Cycle Time or Operation Mode	Representative Maximum Dredging Depth, ft	Average Height of Sampling Tubes Above Center of Cutterhead, ft
Calumet River	Open clamshell	10-cu yd bucket	60 sec with bucket drag bottom smoothing	27	
Duwamish Waterway	Open clamshell	--[1]	--[1]	30	
Lake City	Open clamshell Closed clamshell	3.5-cu yd bucket 4.5-cu yd bucket	60 sec --[1]	35 35	
St. Johns River	Open clamshell Closed clamshell	12-cu yd bucket 15-cu yd bucket	43 sec --[1] (No sweeping)	18 18	

[1] Unavailable data.

Table 3
Dredge and Site Parameters

Site	Idealized Volume for Dredgehead or Bucket, cu ft	Surface Area of Idealized Volume sq ft	Characteristic Length Scale for Dredgehead or Bucket, ft, L or b	Characteristic Settling Velocity 1,000 ft/sec	Observed Source Concentration C at Dredgehead or Bucket, mg/ℓ
Calumet Harbor (Cutterhead)	16.04	24.93	3.94	4.314	--[1]
James River (Cutterhead)	66.54	68.08	6.33	0.906	--
Savannah River	94.25	93.82	7.11	1.083[2]	--
Grays Harbor (without overflow)	10.42	21.98	4.38	2.556	146
Black Rock Harbor	540	--	8.14	3.507	520
Calumet River	540	--	8.14	4.314	75
Duwamish Waterway	--	--	--	0.318	80
Lake City					
open	189	--	5.74	--	55
closed	243	--	6.24		150
St. Johns River					
open	648	--	8.65		250
closed	810	--	9.32	5.143[3]	150

[1] Data unavailable.
[2] 2.5 specific gravity assumed.
[3] From settling column data analysis.

Table 4
Full-Cut Parameter Variation

Site and Type of Cut	Average *u*	Standard Deviation of *u*	*F*	$(L/d) \times 10^{-4}$
Calumet Harbor				
Full cut	-1.050	0.160	0.0892	2.7928
Savannah River				
Partial cut	-0.556	0.545	0.278	9.4223
Buried cut	1.229	0.598	16.94	
Estimated				
Full cut	-0.824[1]	--	0.15	
James River				
Full cut	1.914	0.439	82.1	12.368

[1] Computed from *F*.

Table 5
Full-Cut Dredging Function Correlation Statistics

Data Set	Standard Error in Estimate of log *C*	Number of Observations	r^2
Savannah River			
Partial cut	0.5321	25	0.2826
Buried cut	0.5914	27	0.3208
Partial & buried cut	0.5679	52	0.5661
James River	0.3976	21	0.003
Calumet Harbor	0.1491	12	0.7240
Savannah River partial & buried cut + Calumet Harbor	0.5153	64	0.5714
Savannah River partial & buried cut + Calumet Harbor + James River	0.5619	85	0.5563

Note: C = Resuspended sediment concentration; r^2 = correlation coefficient.

Table 6
Representative Resuspended Sediment Source Strengths for Open-Bucket Clamshell Dredges

Parameter	Black Rock Harbor	Site Calumet River	St. Johns River
b, ft	8.14	8.14	5.74
f_d[1]	0.4	0.4	0.4
f_o[1]	0.1	0.1	0.1
f_u h, ft	20	27	18
T, sec	40	60	43
$V_s \times 10^3$ (ft/sec)	3.507	4.314	5.143
$1 + k_{cb}$[1]	2	2	2
C, mg/ℓ	449	72	285
R, grams/sec	1,684	243	445

[1] Assumed values.

Table 7
Representative Resuspended Sediment Source Strengths For Cutterhead Suction Dredges

	Site		
Parameter	Calumet Harbor	James River	Savannah River
L/d	27,928	123,680	94,223
V_s/V_i	2	0.8	1.6
V_t/V_i	8	9	9
D	1	1	3.2
F	0.0892	82.1	16.94
u	-1.050	1.947	1.229
V	2.848	2.848	2.848
w	1.022	1.022	1.022
V_t, ft/sec	5	4	4
D_{ch}	3	5	6
L_{ch}	2.5	5.08	5
$1 + k_{ch}$	1.75	1.75	1.75
$1 + k'_{ch}$	1.25	1.25	1.25
C, mg/ℓ	5.4	411	594
R, grams/sec	13	2,858	4,413

Appendix A
Notation

a_z	Fraction of cutterhead semi-ellipsoid surface submerged below mudline
A_{ch}	Surface area of cutterhead
A_z	Surface area of the zone of the ellipsoid where $M \neq m$
b	Characteristic size of clamshell bucket
B	Dimensionless dredging depth
c_d	Concentration below bucket during bucket fall
c_u	Concentration below bucket during bucket rise
C	Concentration
C_a	Average concentration in bucket source volume
C_U	Concentration below bucket at top of bucket rise
C_T	Concentration below bucket at end of bucket fall
d	Median grain size
d_f	Cutterhead head penetration
D	Dimensionless cutterhead penetration
D_{ch}	Cutterhead diameter
D_f	Cutterhead penetration at full penetration
D_m	Penetration depth in buried cutting
f'	Fraction of time during bucket fall

f_b	Fraction of cycle time bucket on bottom
f_d	Fraction of cycle time for bucket fall
f_o	Fraction of cycle time bucket out of water
f_u	Fraction of cycle time for bucket rise
F	Dredging function
F_a	Fraction of cutterhead surface exposed on advancing side of cutterhead
F_c	Fraction of source volume surface available for sediment generation
F_n	Fraction of cutterhead surface exposed on nonadvancing side of cutterhead
F_D	Non full cut penetration dredging function
$(F_D)_b$	Buried cut dredging function
$(F_D)_w$	Partial cut dredging function
F_F	Full cut dredging function
h	Dredging depth
k_{cb}	Size factor for diameter of clamshell bucket
k_{ch}	Size factor for diameter of cutterhead
k'_{ch}	Size factor for length of cutterhead
L	Characteristic size of cutterhead
L_{ch}	Cutterhead length
m	Length of minor semi-axis of cutterhead ellipse
m_u	Mass of sediment below bucket
M	Length of major semi-axis of cutterhead ellipse
M_d	Mass flux across clamshell bucket source volume surface
P	Dimensionless cutterhead depth
P_o	Relative penetration at tip of cutterhead ellipse

q' Dimensionless y distance to point of tangency of cutterhead ellipse with penetration line

r Mass rate of sediment release from bucket

R Source strength

S Dimensionless cycle time

t Time

T Clamshell dredge cycle time

u Regression coefficient

v Regression coefficient

v_d Downward velocity of bucket

v_r Radial velocity below fall bucket

v_s Sediment settling velocity

v_u Upward velocity of bucket

V_c Tangential velocity of cutterhead

V_i Intake suction velocity

V_s Swing velocity

V_t Net cutterhead velocity

w Regression coefficient

x Coordinate along major axis of cutterhead ellipse

x_p x-coordinate at point of intersection of mudline with cutterhead ellipse

x_t x-coordinate at point of tangency of cutterhead to penetration line

y Coordinate along minor axis of cutterhead ellipse

y_p y-coordinate at point of intersection of mudline with cutterhead ellipse

y_t y-coordinate at point of tangency of cutterhead to penetration line

$y(0)$ Intercept of penetration line with y axis of cutterhead ellipse

ρ	Density of water
θ	Ladder arm angle
V_{cb}	Volume of clamshell bucket
V_{ch}	Volume of moving resuspended sediment source

Appendix B Abbreviations

BR	Black Rock Harbor site
CH	Calumet Harbor site
CR	Calumet River site
DW	Duwamish Waterway site
IOMT	Improvement of Operation and Maintenance Techniques
GH	Grays Harbor site
JR	James River site
LC	Lake City site
max	maximum
ppt	parts per thousand
SJ	St. Johns River site
SR	Savannah River site
SG	specific gravity
USCS	Universal Soil Classification System

Appendix C Penetration Relations for Cutterhead Dredge

This appendix develops expressions for penetration depth and surface area coverage as a function of penetration depth for a cutterhead dredgehead when full or partial penetration occurs.

The cutterhead is presumed to be semi-ellipsoid in shape, formed by the revolution of an ellipse about its major axis. The cutterhead length L_{ch}[1] equals the length of the major semi-axis of the ellipse M, while the cutterhead diameter D_{ch} equals the length of the minor semi-axis of the ellipse m. For convenience, let $L_{ch} = M$ and $D_{ch}/2 = m$. Thus if an x-,y-coordinate system, as shown in Figure C1, coincides with the major and minor axes of the ellipse, the equation of the ellipse is given by

$$\frac{x^2}{M^2} + \frac{y^2}{m^2} = 1 \tag{C1}$$

The major axis parallels the ladder arm of the dredgehead and is presumed to be at an angle θ with respect to the horizontal. The dredgehead penetrates a vertical distance d_f into the materials being dredged, extending from the mudline downward to the penetration line (i.e., the mudline after dredging). The penetration line is tangent to the lowermost point of the dredgehead. At full penetration the mudline intersects the minor axis of the ellipse at the boundary of the ellipse and $d_f = D_f$. The degree of penetration P is

$$P = d_f/D_f \tag{C2}$$

If $P < 1$, a partial cut exists; if $P = 1$, a full cut exists.

[1] For convenience, symbols are listed in the Notation (Appendix A).

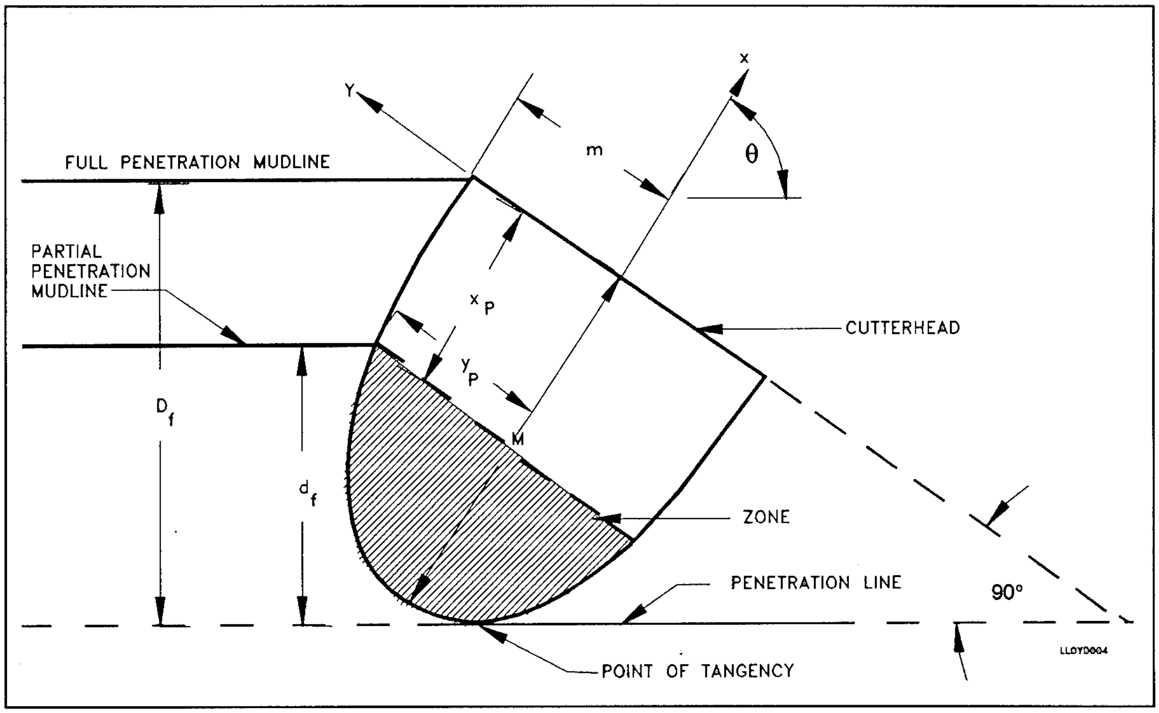

Figure C1. Definition sketch for cutterhead penetration

Penetration Depth For Full Penetration

The slope of a tangent to the cutterhead surface, by differentiation of Equation C1, is

$$dy/dx = -(x\ m^2)/(y\ M^2) \tag{C3}$$

Therefore, since the ladder arm is at an angle θ with respect to the horizontal, the equation of the mudline at full penetration is given by

$$y = -x \tan \theta + m \tag{C4}$$

The point of tangency of the penetration line to the cutterhead surface is obtained by using the equation for the ellipse, Equation C1, and the slope of a tangent to the ellipse, Equation C2. Combining these two equations yields

$$x = M^2\ y \tan \theta / m^2 \tag{C5}$$

Substituting for x in Equation C1 yields

$$(y/m)^2[(M/m)^2 \tan^2\theta + 1] = 1 \tag{C6}$$

Thus if x_t and y_t are the x- and y-coordinates of the point of tangency of the penetration line to the ellipse, q',

$$y_t/m = -q' \tag{C7}$$

$$x_t/M = -(1 - q'^2)^{1/2} \tag{C8}$$

in which

$$1/q' = [1 + (M/m)^2 \tan^2\theta]^{1/2} \tag{C9}$$

Note that negative roots for y_t/m and x_t/M have been selected in Equations C7 and C8 because both y_t and x_t must be negative. Because the penetration line is at an angle θ-relative to the x-axis and passes through the point (x_t, y_t), the equation of the penetration line is

$$y = -x\tan\theta + y_t + x_t\tan\theta \tag{C10}$$

By similar triangles, it follows that at $x = 0$

$$\cos\theta = \frac{D_f}{b - y(0)} \tag{C11}$$

in which y(0) is the intercept of the penetration line with the y-axis (i.e., $x = 0$). Therefore, using Equation C10 evaluated at $x = 0$ yields the cutter-head penetration at full penetration D_f

$$D_f = \cos\theta\,[m - (y_t + x_t\tan\theta)] \tag{C12}$$

or, using Equations C7 and C8,

$$D_f = (D_{ch}/2)\cos\theta\,[1 + (1/q')] \tag{C13}$$

in which, consistent with Equation C9,

$$1/q' = \left\{1 + 2\left[(L_{ch}/D_{ch})\tan\theta\right]^2\right\}^{1/2} \tag{C14}$$

Surface Area For Partial Penetration

For partial penetration, i.e., $P < 1$, the mudline intersects the cutterhead ellipse at a vertical distance d_f above the penetration line. The equation of the mudline is obtained by vertically shifting the equation for the penetration line. Thus, the equation of the mudline is

$$y - d_f \cos\theta = -\tan\theta\,(x - d_f \sin\theta) + y_t + x_t \tan\theta \tag{C15}$$

Rearranging this equation and using Equations C7 and C8 yields

$$(y/m) + (x/M)[(1/q'^2) - 1]^{1/2} - (d_f \cos\theta/b)(\tan^2\theta + 1) = -1/q' \tag{C16}$$

At the point $(x,y) = (x_p, y_p)$ where the mudline intersects the cutterhead ellipse, from Equation C1

$$x_p/M = -[1 - (y_p/m)^2]^{1/2} \tag{C17}$$

Therefore, setting $x = x_p$ and $y = y_p$ in Equation C16 and using Equation C17 yields

$$\begin{aligned}&(y_p/m) - [1 - (y_p/m)^2]^{1/2}[(1/q'^2) - 1]^{1/2}\\ &- (d_f \cos\theta/m)(\tan^2\theta + 1) + 1/q' = 0\end{aligned} \tag{C18}$$

Now, using Equations C2 and C13

$$P = d_f/D_f = \frac{d_f}{m\cos\theta[1 + (1/q')]} \tag{C19}$$

Introducing this into Equation C18 yields after simplification

$$\begin{aligned}&(y_p/m) - \{[1 - (y_p/m)^2][(1/q'^2) - 1]\}^{1/2}\\ &\qquad + (1/q') = P[1 + (1/q')]\end{aligned} \tag{C20}$$

which can be further simplified to yield the quadratic equation

$$\begin{aligned}&(y_p/m)^2 - 2q'[P(q' + 1) - 1](y_p/m)\\ &+ [P(q' + 1) - 1]^2 + q'^2 - 1 = 0\end{aligned} \tag{C21}$$

Thus

$$y_p/m = q'[P(q' + 1) - 1] + \left([1 - q'^2]\right.$$
$$\left.\{1 - [P(q' + 1) - 1]^2\}\right)^{1/2} \qquad \text{(C22a)}$$

or

$$2y_p/D_{ch} = q'[P(q' + 1) - 1] + \left((1 - q'^2)\right.$$
$$\left.\{1 - [P(q' + 1) - 1]^2\}\right)^{1/2} \qquad \text{(C22b)}$$

in which the positive root of the quadratic equation has been taken since the mudline intersects the cutterhead ellipse on the upper portion of the perimeter of the ellipse. x_p/M can be determined from Equation C17 using Equation C22. Note that if $P = 1$, Equation C22 gives $y_p/m = 1$.

The symmetric volume of the ellipsoid contained between the planes $x = -M$ and $x = x_p$, where $x_p < 0$, is the "zone" of the ellipse; when $x_p = 0$, the zone of the ellipsoid is one-half of the total ellipsoid. If the ellipsoid were a sphere with radius $= m = M$, the surface area of the zone would be $[2\ m\pi\ (M + x_p)]$. As an approximation, therefore, the surface area, A_z, of the zone of the ellipsoid for M not equal to m is taken as

$$A_z = 2\ m\ \pi\ (M + x_p) \qquad \text{(C23)}$$

When $P = 1$, $A_z = (2\pi mM)$ since $x_p = 0$ when $P = 1$. Therefore, if a_z is the area of the zone for $P < 1$ relative to the area when $P = 1$, i.e., if

$$a_z = A_z/A_z(P = 1) \qquad \text{(C24)}$$

then

$$a_z = (M + x_p)/M = 1 + (xP/M) \qquad \text{(C25)}$$

or

$$a_z = 1 - [1 - (y_p/m)^2]^{1/2} = 1 - [1 - (2y_p/D_{ch})^2]^{1/2} \qquad \text{(C26)}$$

The relative area a_z defined by Equation C25 varies with the relative penetration P. The expression provided by Equation C25 is correct for values of P such that the intersection of the mudline with the cutterhead ellipse lies above the tip of ellipsoid at $(x_p, y_p) = (-M,O)$. For values of P that cause the intersection point to conceptually lie below the tip, an alternative expression for a_z obtains. However, for practical purposes, a_z can be approximated as zero for values of P that cause the mudline to intersect below the tip of the cutterhead ellipse. Let the value of P for which $a_z = 0$ in Equation C25 be P_o; P_o can be conveniently found from Equation C20 by setting y_p/b to zero. Thus

$$P_o = [1/(1 + q')] - [(1 - q')/(1 + q')]^{1/2} \tag{C27}$$

in which a negative square root in Equation C26 has been selected because P_o must be less than 1.

Appendix D
Background Concentrations at James River, 1982

Appendix D. Background Concentrations At James River, 1982

Date (dy/mo/yr)	Time	Distance Upstream of Dredge Along Dredging Axis (ft)	Sample Depth (ft)	Total Suspended Sediment mg/ℓ
09-Jun-82	1207	-6600	5	39
09-Jun-82	1205	-6600	10	37
09-Jun-82	1204	-6600	15	43
09-Jun-82	1203	-6600	20	46
09-Jun-82	1201	-6600	25	50
09-Jun-82	1200	-6600	32.5	51
09-Jun-82	1326	-6600	5	40
09-Jun-82	1325	-6600	10	40
09-Jun-82	1324	-6600	15	45
09-Jun-82	1323	-6600	20	33
09-Jun-82	1321	-6600	25	37
09-Jun-82	1318	-6600	33	57
10-Jun-82	846	-7600	5	48
10-Jun-82	845	-7600	10	56
10-Jun-82	843	-7600	15	62

(Continued)

Appendix D. (Continued)

Date (dy/mo/yr)	Time	Distance Upstream of Dredge Along Dredging Axis (ft)	Sample Depth (ft)	Total Suspended Sediment mg/ℓ
10-Jun-82	842	-7600	20	88
10-Jun-82	837	-7600	25	136
10-Jun-82	836	-7600	32	184
10-Jun-82	1450	-8000	5	72
10-Jun-82	1447	-8000	10	79
10-Jun-82	1446	-8000	15	98
10-Jun-82	1444	-8000	20	109
10-Jun-82	1443	-8000	25	110
10-Jun-82	1441	-8000	30	133
11-Jun-82	744	-11700	5	35
11-Jun-82	742	-11700	10	25
11-Jun-82	739	-11700	15	36
11-Jun-82	737	-11700	20	33
11-Jun-82	735	-11700	25	31
11-Jun-82	734	-11700	32.5	48

(Continued)

Appendix D. (Concluded)

Date (dy/mo/yr)	Time	Distance Upstream of Dredge Along Dredging Axis (ft)	Sample Depth (ft)	Total Suspended Sediment mg/ℓ
11-Jun-82	1417	-12000	15	30
11-Jun-82	1415	-12000	20	33
11-Jun-82	1410	-12000	32.5	43
11-Jun-82	753	-10000	10	33
11-Jun-82	748	-10000	20	36
11-Jun-82	746	-10000	25	63
11-Jun-82	744	-10000	32	90
11-Jun-82	1424	-7900	5	29
14-Jun-82	917	-7900	5	30
14-Jun-82	859	-7900	15	32
14-Jun-82	852	-7900	30.5	42

Appendix E
Dustpan Suction Dredge Concentrations at James River, 1982

Appendix E. Dust Pan Suction Dredge Concentrations At James River, 1982

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sampling Depth (ft)	Pass	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Swing Speed (fps)	Sampling Tube	Total Suspended Sediment (mg/ℓ)	Estimated Background Concentrated (mg/ℓ)
27-Jun-82	830	26.5	20	1	410	2.1	272	2.1	L2	132	84
27-Jun-82	845	28	18.75	2		2.1	272	2.1	R3	250	84
27-Jun-82	850	28	17.25	2		2.1	272	2.1	R4	216	84
27-Jun-82	855	28	18.75	2		2.1	272	2.1	R5	254	84
27-Jun-82	920	30	19.25	3	340	2.4	290	2.4	L4	258	84
27-Jun-82	925	30	23.5	3		2.4	290	2.4	L2	394	92
27-Jun-82	1030	25.5	16.25	1	320	1.7	243	1.7	R1	204	67
27-Jun-82	1130	27.5	18.25	1	330	1.6	243	1.6	L5	142	84
27-Jun-82	1145	28	18.75	2		1.6	243	1.6	L3	112	84
27-Jun-82	1155	28	17.25	2		1.0	240	1.0	L4	108	48
27-Jun-82	1205	28	18.75	2		1.0	240	1.0	R5	88	48
27-Jun-82	1230	29	22.5	3	345	1.0	240	1.0	L2	120	48
27-Jun-82	1235	29	19.75	3		1.2	120	1.2	R3	82	70
27-Jun-82	1240	29	19.75	3		1.2	120	1.2	L5	68	48
27-Jun-82	1255	30	20.75	4		1.0	80	1.0	R5	68	48

(Continued)

Appendix E. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sampling Depth (ft)	Pass	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Swing Speed (fps)	Sampling Tube	Total Suspended Sediment (mg/ℓ)	Estimated Background Concentrated (mg/ℓ)
27-Jun-82	1300	30	19.25	4		1.0	80	1.0	L4	62	48
27-Jun-82	1305	30	23.5	4		0.8	80	0.8	L2	64	53
27-Jun-82	1310	30	23.5	4		0.8	80	0.8	L2	87	53
27-Jun-82	1425	26	15.25	1	370	1.8	80	1.8	R2	154	67
27-Jun-82	1430	26	15.25	1		1.8	80	1.8	R4	158	67
27-Jun-82	1435	26	16.75	1		1.8	80	1.8	R1	178	67
27-Jun-82	1455	28	18.75	2		1.6	84	1.6	R1	240	84
27-Jun-82	1505	28	17.25	2		1.6	84	1.6	L4	258	67
27-Jun-82	1520	28	18.75	2		1.6	84	1.6	R5	168	84
27-Jun-82	1530	28	18.75	2	400	1.6	84	1.6	L3	322	84
27-Jun-82	1545	30	19.25	3	430	1.6	84	1.6	R4	266	84
27-Jun-82	1550	30	19.25	3		1.6	84	1.6	R4	234	84
28-Jun-82	915	28	18.75	3	575	2.0	270	2.0	R1	115	84
28-Jun-82	925	28	18.75	3		2.0	275	2.0	L3	148	84
28-Jun-82	930	28	18.75	3		2.0	275	2.0	L5	214	84

(Continued)

Appendix E. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sampling Depth (ft)	Pass	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Swing Speed (fps)	Sampling Tube	Total Suspended Sediment (mg/ℓ)	Estimated Background Concentrated (mg/ℓ)
28-Jun-82	1130	28	18.75	3	340	2.0	270	2.0	R1	115	84
28-Jun-82	1145	28	18.75	3		2.0	270	2.0	R3	142	84
28-Jun-82	1150	28	18.75	3		2.0	270	2.0	R5	128	84
28-Jun-82	1240	29	19.75	4	320	1.0	270	1.0	R1	92	49
28-Jun-82	1245	29	19.75	4		1.0	270	1.0	L3	110	49
28-Jun-82	1250	29.5	18.75	4		1.0	270	1.0	R4	88	49
28-Jun-82	1305	29.5	20.25	4		1.0	270	1.0	R5	76	49
28-Jun-82	1315	29.5	18.75	4		1.0	270	1.0	L4	65	49
28-Jun-82	1320	29.5	20.25	4		1.0	270	1.0	R5	70	49
28-Jun-82	1425	25	14.25	1		1.3	100	1.3	R2	60	60
28-Jun-82	1430	25	15.75	1		1.3	100	1.3	L3	88	67
28-Jun-82	1435	25	14.25	1	325	1.3	100	1.3	R4	74	67
28-Jun-82	1450	25	15.75	1		1.5	90	1.5	R5	112	67
28-Jun-82	1455	25	15.75	1		1.5	90	1.5	R3	90	67
28-Jun-82	1500	25	15.75	1		1.5	90	1.5	R5	110	67

(Continued)

Appendix E. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sampling Depth (ft)	Pass	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Swing Speed (fps)	Sampling Tube	Total Suspended Sediment (mg/ℓ)	Estimated Background Concentrated (mg/ℓ)
28-Jun-82	1505	25	15.75	1		1.5	90	1.5	R1	104	67
28-Jun-82	1530	27	17.75	2		1.5	90	1.5	L3	154	84
29-Jun-82	920	24	13.25	1	1200	1.8	275	1.8	L4	42	42
29-Jun-82	940	25	15.75	2		1.8	275	1.8	R5	88	67
29-Jun-82	945	25	18.5	2		1.6	275	1.6	L2	112	84
29-Jun-82	948	26.5	16.75	2		1.8	275	1.8	L3	86	67
29-Jun-82	1000	27	17.75	3		1.6	275	1.6	L5	144	84
29-Jun-82	1005	27	20.5	3		1.6	275	1.6	L2	206	84
29-Jun-82	1008	27	17.75	3		1.6	275	1.6	R3	108	84
29-Jun-82	1010	28	17.25	3		1.8	275	1.8	R4	98	67
29-Jun-82	1025	28	18.75	4		1.8	275	1.8	R3	170	84
29-Jun-82	1027	28	18.75	4		1.8	275	1.8	R1	106	84
29-Jun-82	1030	28	18.75	4	900	1.8	275	1.8	R5	170	84
29-Jun-82	1240	24.5	15.25	1	575	2.4	260	2.4	L3	170	67

(Continued)

Appendix E. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sampling Depth (ft)	Pass	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Swing Speed (fps)	Sampling Tube	Total Suspended Sediment (mg/ℓ)	Estimated Background Concentrated (mg/ℓ)
29-Jun-82	1243	24.5	13.25	1	575	2.4	260	2.4	L4	170	67
29-Jun-82	1309	24.5	15.25	1		2.1	245	2.1	R1	82	67
29-Jun-82	1315	24.5	15.25	1		2.1	245	2.1	R3	106	67
29-Jun-82	1318	24.5	15.25	1		2.1	245	2.1	L5	168	67
29-Jun-82	1343	27	17.75	2		2.1	245	2.1	R3	84	84
29-Jun-82	1345	27	16.25	2	345	2.1	245	2.1	R4	104	67
29-Jun-82	1410	28	18.75	3		0.9	260	0.9	R1	72	49
29-Jun-82	1412	28	18.75	3		0.9	260	0.9	R3	82	49
29-Jun-82	1415	28	18.75	3		0.9	260	0.9	R5	84	49
29-Jun-82	1445	29	19.75	4	330	0.5	125	0.5	R3	56	44
29-Jun-82	1540	24	14.75	1	345	1.0	85	1.0	R1	44	44
29-Jun-82	1546	24	14.75	1		1.0	85	1.0	L3	78	48
29-Jun-82	1550	24	13.25	1		1.0	85	1.0	R4	62	48
29-Jun-82	1613	26.5	17.25	2		1.2	90	1.2	R1	80	48

(Continued)

Appendix E. (Concluded)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sampling Depth (ft)	Pass	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Swing Speed (fps)	Sampling Tube	Total Suspended Sediment (mg/ℓ)	Estimated Background Concentrated (mg/ℓ)
29-Jun-82	1616	26.5	20	2		1.2	90	1.2	L2	88	49
29-Jun-82	1620	26.5	17.25	2	370	1.2	90	1.2	L5	92	71

Appendix F
Cutterhead Suction Dredge Concentrations at James River, 1982

Appendix F. Cutterhead Suction Dredge Concentrations At James River, 1982

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sample Depth (ft)	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Pass	Sampling Tube*	Total Suspended Sediment (mg/ℓ)	Dredge Discharge cy/s	Estimated Background Concentration (mg/ℓ)	Swing Direction (L:Left) R:Right)**	Cutter RPM
09-Jun-82	1230	33.6	1.00	110	0.4	90	0	1 L	86	102			32
09-Jun-82	1232	33.6	24.30	160	0.4	90	8	1.1 L	80	103	54	L	32
09-Jun-82	1233	33.6	23.35	160	0.4	90	8	2.1 R	63	100	54	L	20
09-Jun-82	1235	33.7	23.40	160	0.4	90	8	1.2 L	61	104	54	L	32
09-Jun-82	1236	33.7	23.50	160	0.4	90	8	2.2 R	73	104	54	L	32
09-Jun-82	1312	33.9	1.00	210	1.4	84	9	2 R	51	100		R	28
09-Jun-82	1314	33.9	24.50	195	0.8	78	9	1.1 L	50	98	50	R	32
09-Jun-82	1316	33.9	23.70	195	0.8	78	9	1.2 L	58	103	49	R	20
09-Jun-82	1318	33.9	26.40	195	0.8	78	9	1.3 L	72	100	49	R	32
09-Jun-82	1319	33.9	26.40	195	0.8	78	9	2.3 R	81	100	49	R	32
09-Jun-82	1427	34.0	1.00	200	1.2	90	8	1 L	82	100		L	20
09-Jun-82	1432	34.0	24.70	210	1.6	76	8	1.1 L	91	100	91	L	20
09-Jun-82	1433	34.0	24.70	210	1.6	76	8	2.1 R	108	102	92	L	20

(Continued)

* Sampling Tube Identification: L, R indicates left or right tube; 1 or 2 indicates near surface sample; 1.x indicates "x" number tube on left and 2.x indicates "x" number tube on right of sampling array rake at dredgehead.

** Swing speeds estimated from reported times to make swing to be 0.863 f/s in left direction and 0.465 in right direction.

Appendix F. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sample Depth (ft)	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Pass	Sampling Tube*	Total Suspended Sediment (mg/ℓ)	Dredge Discharge cy/s	Estimated Background Concentration (mg/ℓ)	Swing Direction (L:Left) R:Right)**	Cutter RPM
09-Jun-82	1436	34.0	26.50	210	1.6	76	8	1.3 L	106	102	84	L	
09-Jun-82	1438	34.0	26.50	210	1.6	76	8	2.3 R	83	100	83	L	32
10-Jun-82	917	32.8	1.00	190	1.6	275	8	1 L	63	100		L	35
10-Jun-82	918	32.8	23.50	185	1.5	280	8	2.1 R	121	100	92	L	35
10-Jun-82	923	32.8	22.60	185	1.5	280	8	2.2 R	157	90	84	L	37
10-Jun-82	924	32.8	25.30	185	1.5	280	8	1.3 L	119	100	84	L	37
10-Jun-82	925	32.8	25.30	185	1.5	280	8	2.3 R	202	100	84	L	37
10-Jun-82	1022	32.8	1.00	180	1.7	280	9	2 R	79	100		R	37
10-Jun-82	1024	32.8	23.50	180	1.7	280	9	1.1 L	194	100	92	R	37
10-Jun-82	1025	32.7	23.40	180	1.7	280	9	2.1 R	107	100	92	R	37
10-Jun-82	1026	32.7	22.40	180	1.7	280	9	1.2 L	116	100	84	R	37
10-Jun-82	1028	32.7	25.20	180	1.7	280	9	1.3 L	242	95	84	R	40
10-Jun-82	1143	33.0	1.00	175	0.9	272	8	1 L	82	104		L	32
10-Jun-82	1146	33.0	23.70	180	0.9	272	8	1.1 L	107	85	53	L	35

(Continued)

Appendix F. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sample Depth (ft)	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Pass	Sampling Tube*	Total Suspended Sediment (mg/ℓ)	Dredge Discharge cy/s	Estimated Background Concentration (mg/ℓ)	Swing Direction (L:Left) R:Right)**	Cutter RPM
10-Jun-82	1147	33.0	22.80	180	0.9	272	8	1.2 L	127	100	49	L	37
10-Jun-82	1149	33.1	22.60	180	0.9	272	9	2.2 R	93	100	49	R	28
10-Jun-82	1150	33.1	25.60	180	0.9	272	9	1.3 L	106	98	49	R	37
10-Jun-82	1305	33.6	1.00	190	0.5	102	9	2 R	65	102		R	28
10-Jun-82	1308	33.6	24.25	190	1	90	8	2.1 R	134	100	53	L	32
10-Jun-82	1309	33.6	23.40	190	1	90	8	1.2 L	117	100	49	L	32
10-Jun-82	1310	33.6	23.40	190	1	90	8	2.2 R	58	95	49	L	37
10-Jun-82	1311	33.6	26.10	170	1	90	9	1.3 L	71	94	49	R	37
10-Jun-82	1425	33.8	1.00	290	1.8	78	8	1 L	75	102		L	?, but dredging
10-Jun-82	1428	33.8	24.50	290	1.2	70	8	2.1 R	218	100	52	L	?, but dredging
10-Jun-82	1429	33.8	23.60	290	1.2	70	8	1.2 L	101	103	49	L	?, but dredging
10-Jun-82	1230	33.8	23.60	290	1.2	70	8	2.2 R	100	100	49	L	?, but dredging
10-Jun-82	1432	33.8	26.30	260	1.2	70	9	1.3 L	116	95	49	L	?, but dredging
11-Jun-82	1453	34.0	1.00	190	0.4	80	9	2 R	40	105		R	20

(Continued)

Appendix F. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sample Depth (ft)	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Pass	Sampling Tube*	Total Suspended Sediment (mg/ℓ)	Dredge Discharge cy/s	Estimated Background Concentration (mg/ℓ)	Swing Direction (L:Left) R:Right)**	Cutter RPM
11-Jun-82	1455	34.0	24.70	210	0.5	95	8	1.1 L	127	106	54	L	20
11-Jun-82	1456	34.0	24.70	210	0.5	95	8	2.1 R	197	103	54	L	20
11-Jun-82	1458	34.0	23.80	210	0.5	95	8	2.2 R	68	90	44	L	20
11-Jun-82	1459	34.0	26.50	210	0.5	95	9	1.34 L	74	100	44	R	20
11-Jun-82	1534	34.1	24.80	220	0.7	90	8	1.1 L	144	103	54	L	20
11-Jun-82	1536	34.1	24.80	220	0.7	90	8	2.1 R	100	106	54	L	28
11-Jun-82	1538	34.1	23.90	220	0.7	90	8	1.2 L	85	104	54	L	20
11-Jun-82	1539	34.1	23.90	220	0.7	90	9	2.2 R	55	102	44	R	32
11-Jun-82	1540	34.1	26.60	210	0.7	90	9	1.3 L	82	105	44	R	37
11-Jun-82	1610	34.2	1.00	200	1.4	92	9	2 R	47	106		R	?, but dredging
11-Jun-82	1613	34.2	24.90	200	1.2	82	9	2.1 R	107	103	53	R	?, but dredging
11-Jun-82	1614	34.2	24.00	200	1.2	82	8	2.2 R	76	110	49	L	?, but dredging
11-Jun-82	1616	34.2	26.70	200	1.2	82	8	1.3 L	90	102	49	L	?, but dredging
11-Jun-82	1617	34.2	26.70	200	1.2	82	8	2.3 R	80	100	49	R	?, but dredging

(Continued)

Appendix F. (Continued)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sample Depth (ft)	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Pass	Sampling Tube*	Total Suspended Sediment (mg/ℓ)	Dredge Discharge cy/s	Estimated Background Concentration (mg/ℓ)	Swing Direction (L:Left) R:Right)**	Cutter RPM
12-Jun-82	1004	33.2	23.90	215	1.4	275	9	1.1 L	129	100	92	R	20
12-Jun-82	1006	33.2	23.00	215	1.4	275	8	2.2 R	88	101	84	L	35
12-Jun-82	1007	33.2	25.70	215	1.4	275	8	1.3 L	127	103	84	L	32
12-Jun-82	1048	33.0	23.70	195	1	278	8	2.1 R	169	95	53	L	28
12-Jun-82	1050	33.0	22.80	195	1	278	8	1.2 L	127	100	49	L	35
12-Jun-82	1052	33.0	25.50	195	1	278	8	1.3 L	156	105	49	L	20
12-Jun-82	1054	33.0	25.50	195	1	278	9	2.3 R	177	103	49	R	35
12-Jun-82	1208	33.0	23.70	165	0.6	275	9	1.1 L	170	102	54	R	32
12-Jun-82	1209	33.0	23.70	165	0.6	275	8	2.1 R	116	102	54	L	32
12-Jun-82	1212	33.0	25.50	165	0.6	275	8	1.3 L	158	96	44	L	35
12-Jun-82	1249	33.1	23.80	160	0.6	276	8	2.1 R	96	105	54	L	28
12-Jun-82	1250	33.1	22.85	160	0.6	276	8	1.2 L	72	104	44	L	28
12-Jun-82	1253	33.1	25.60	160	0.6	276	8	2.3 R	72	95	44	L	37
12-Jun-82	1403	33.7	24.40	150	0.4	140	8	2.1 R	201	106	54	L	20
12-Jun-82	1404	33.7	23.50	150	0.4	140	9	1.2 L	95	100	44	R	28

(Continued)

Appendix F. (Concluded)

Date (dy/mo/yr)	Time	Dredging Depth (ft)	Sample Depth (ft)	Salinity (ppt)	Current Speed (fps)	Current Azimuth (deg)	Pass	Sampling Tube*	Total Suspended Sediment (mg/ℓ)	Dredge Discharge cy/s	Estimated Background Concentration (mg/ℓ)	Swing Direction (L:Left) R:Right)**	Cutter RPM
12-Jun-82	1406	33.7	26.20	150	0.4	140	9	1.3 L	133	98	44	R	35
12-Jun-82	1534	33.8	26.30	170	0.8	90	9	1.3 L	52	105	49	R	?, but dredging
12-Jun-82	1535	33.8	26.30	170	0.8	90	9	2.3 R	47	102	47	R	?, but dredging
12-Jun-82	1612	33.9	24.60	215	0.8	90	8	1.1 L	98	100	53	L	?, but dredging
12-Jun-82	1613	33.9	24.60	210	0.8	90	9	2.1 R	145	95	53	R	?, but dredging

Appendix G
Background Concentrations at Savannah River, 1983

Appendix G. Background Concentrations at Savannah River, 1983

Sample Number	Date (dy/mo/yr)	Time	Estimated Background Concentration at Sampling Tube During Dredge Operation — Sampling Tube 1	2	3	4	5
D-1-5	07-Jul-83	1145	54.3		57.4		54.3
D-1-6	07-Jul-83	1245	54.3	60.5	57.4	60.5	54.3
D-2B-1	09-Jul-83	730	55.0	60.8	57.9	60.8	55.0
D-2B-2	09-Jul-83	930	55.1	60.8	58.0	60.8	55.1
D-2-1	09-Jul-83	945	55.8	61.2	58.5	61.2	55.8
D-2B-3	09-Jul-83	1030	54.6	60.6	57.6	60.6	54.6
D-2-2	09-Jul-83	1050	54.6	60.6	57.6	60.6	54.6
D-2-3	09-Jul-83	1415	53.5	60.1	56.8	60.1	53.5
D-2-4	09-Jul-83	1515	53.5	60.1	56.8	60.1	53.5
D-2-5	09-Jul-83	1615	53.5	60.1	56.8	60.1	53.5
D-2-6	09-Jul-83	1715	53.5	60.1	56.8	60.1	53.5
D-4-1	13-Jul-83	630	53.1	59.8	56.4	59.8	53.1
D-4-2	13-Jul-83	730	52.7	59.7	56.2	59.7	52.7
D-4-3	13-Jul-83	830	54.0	60.3	57.2	60.3	54.0
D-4-4	13-Jul-83	930	54.0	60.3	57.2	60.3	54.0

(Continued)

Appendix G. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Estimated Background Concentration at Sampling Tube During Dredge Operation — Sampling Tube 1	2	3	4	5
D-4-5	13-Jul-83	1030	55.3	61.0	58.1	61.0	55.3
D-4-6	13-Jul-83	1125	55.3	61.0	58.1	61.0	55.3
D-4-7	13-Jul-83	1230	55.6	61.1	58.3	61.1	55.6
D-5-3	14-Jul-83	1100	55.1	60.8	58.0	60.8	55.1
D-5-4	14-Jul-83	1230	56.0	61.3	58.6	61.3	56.0
D-5-5	14-Jul-83	1300	56.0	61.3	58.6	61.3	56.0
D-5-6	14-Jul-83	1400	55.3	61.0	58.1	61.0	55.3
D-5-7	14-Jul-83	1505	55.3	61.0	58.1	61.0	55.3
D-5-8	14-Jul-83	1600	55.3	61.0	58.1	61.0	55.3
D-5-9	14-Jul-83	1645	54.0	60.3	57.2	60.3	54.0
D-3-2	10-Jul-83	835	55.8	61.2	58.5	61.2	55.8
D-3-3	10-Jul-83	930	55.8	61.2	58.5	61.2	55.8
D-3-4	10-Jul-83	1030	55.8	61.2	58.5	61.2	55.8
D-3-5	10-Jul-83	1300	54.6	60.6	57.6	60.6	54.6
D-3-6	10-Jul-83	1400	53.7	60.2	56.9	60.2	53.7

(Continued)

Appendix G. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Estimated Background Concentration at Sampling Tube During Dredge Operation: Sampling Tube 1	2	3	4	5
D-3-7	10-Jul-83	1500	53.4	60.0	56.7	60.0	53.4
D-6-1	24-Jul-83	700	53.9	60.2	57.0	60.2	53.9
D-6-2	24-Jul-83	800	54.6	60.6	57.6	60.6	54.6
D-6-3	24-Jul-83	915	54.6	60.6	57.6	60.6	54.6
D-6-4	24-Jul-83	1000	54.6	60.6	57.6	60.6	54.6
D-6-5	24-Jul-83	1145	54.3	60.5	57.4	60.5	54.3
D-6-6	24-Jul-83	1235	53.4	60.0	56.7	60.0	53.4
D-6-7	24-Jul-83	1330	51.1	58.9	55.0	58.9	51.1
D-7-1	25-Jul-83	700	51.6	59.1	55.3	59.1	51.6
D-7-2	25-Jul-83	800	54.6	60.6	57.6	60.6	54.6
D-7-3	25-Jul-83	900	54.6	60.6	57.6	60.6	54.6
D-7-4	25-Jul-83	1000	54.6	60.6	57.6	60.6	54.6
D-7-5	25-Jul-83	1100	54.0	60.3	57.2	60.3	54.0
D-7-6	25-Jul-83	1200	53.7	60.2	56.9	60.2	53.7
D-7-7	25-Jul-83	1300	53.2	59.9	56.6	59.9	53.2

(Concluded)

Appendix G. (Concluded)

Sample Number	Date (dy/mo/yr)	Time	Estimated Background Concentration at Sampling Tube During Dredge Operation — Sampling Tube 1	2	3	4	5
D-7-8	25-Jul-83	1400	52.0	59.3	55.6	59.3	52.0
D-7-9	25-Jul-83	1500	52.0	59.3	55.6	59.3	52.0
D-8-1	26-Jul-83	700	54.8	60.7	57.8	60.7	54.8
D-8-2	26-Jul-83	900	55.8	61.2	58.5	61.2	55.8
D-8-6	26-Jul-83	1300	55.1	60.8	58.0	60.8	55.1
D-8-7	26-Jul-83	1400	54.8	60.7	57.8	60.7	54.8
D-8-8	26-Jul-83	1500	54.3	60.5	57.4	60.5	54.3

Appendix H Cutterhead Suction Dredge Concentrations at Savannah River, 1983

Appendix H. Cutterhead Suction Dredge Concentrations at Savannah River, 1983

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-1-1	07-Jul-83	745			RL				26.87	13.87	34.33	16.80	33.93
D-1-1	07-Jul-83	755					12.8						
D-1-1	07-Jul-83	810					12.8						
D-1-1	07-Jul-83	820				3.90		0.71					
D-1-1	07-Jul-83	825					14.4						
D-1-1	07-Jul-83	840					14.4						
D-1-2	07-Jul-83	845			LR				875.60		39.07	17.80	25.07
D-1-2	07-Jul-83	855					14.4						
D-1-2	07-Jul-83	910					15.2						
D-1-2	07-Jul-83	925					15.2						
D-1-2	07-Jul-83	930				3.90		0.54					
D-1-2	07-Jul-83	940					15.2						
D-1-3	07-Jul-83	945			RL				41.75	22.93	28.47	17.40	23.80
D-1-3	07-Jul-83	955					14.4						

(Continued)

* Cut type: P,f partial cut, buried cut otherwise

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-1-3	07-Jul-83	1015					16.9						
D-1-3	07-Jul-83	1030				4.00	15.2	0.69					
D-1-4	07-Jul-83	1045			RL				50.93	25.70	64.93	20.93	12.27
D-1-4	07-Jul-83	1115					14.4						
D-1-4	07-Jul-83	1100					14.4						
D-1-4	07-Jul-83	1130					14.4						
D-1-4	07-Jul-83	1135				3.90		0.69					
D-1-5	07-Jul-83	1145	P		LR				536.60	20.00	22.27	26.47	103.60
D-1-6	07-Jul-83	1245	P		LR		15.2		76.80	11.70	85.00	17.55	33.33
D-1-6	07-Jul-83	1300	P				15.2						
D-1-6	07-Jul-83	1305	44.0/P	40.14		3.90		0.74					
D-1-6	07-Jul-83	1315					15.2						
D-1-6	07-Jul-83	1330					16.9						
D-1-7	07-Jul-83	1345			RL					47.53	36.20	48.50	45.30
D-1-7	07-Jul-83	1405				3.90		0.84					
D-1-7	07-Jul-83	1430					15.2						

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-1-7	07-Jul-83	1445					16.9						
D-1-8	07-Jul-83	1450			LR				249.00	597.00	653.84	911.33	882.50
D-1-8	07-Jul-83	1500					16.9						
D-1-8	07-Jul-83	1505				3.95		0.00					
D-1-8	07-Jul-83	1515					15.2						
D-1-8	07-Jul-83	1530					15.2						
D-1-8	07-Jul-83	1545					15.2						
D-1-8	07-Jul-83	1610	46.5	42.95									
D-2B-1	09-Jul-83	730	P		RL	3.63		1.20	143.30	177.50	237.10	154.00	182.20
D-2B-1	09-Jul-83	745	P				14.1						
D-2B-1	09-Jul-83	800	P				13.3						
D-2B-1	09-Jul-83	815	P				13.3						
D-2B-1	09-Jul-83	900	47.0/P	43.52		2.06	13.3	0.00					
D-2B-1	09-Jul-83	918	47.0/P	43.52		0.00	13.3	0.96					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-2B-2	09-Jul-83	930	P		LR	3.77	13.3	1.10	73.30	57.20	71.80	76.20	19.60
D-2-1	09-Jul-83	945	50.0/P	47.10	LR					34.73	77.10	95.30	47.00
D-2B-2	09-Jul-83	948	45.5/P	41.81		2.13	13.3	0.99					
D-2B-2	09-Jul-83	1000	P				14.1						
D-2B-2	09-Jul-83	1015	45.0/P	41.25		5.02	14.1	1.01					
D-2B-2	09-Jul-83	1020	P		RL					11.40			
D-2B-3	09-Jul-83	1030	P		LR		14.1		1227.70		48.80	104.60	167.80
D-2B-3	09-Jul-83	1045	45.0/P	41.25									
D-2B-3	09-Jul-83	1050	P				14.1						
D-2-2	09-Jul-83	1050	P		RL				394.50	142.20	189.80	183.20	393.25
D-2-2	09-Jul-83	1100	P				14.1						
D-2B-3	09-Jul-83	1101	P				13.0						
D-2B-3	09-Jul-83	1115	43.0/P	39.05		1.97	13.3	1.00					
D-2B-3	09-Jul-83	1130	P				13.3						
D-2B-3	09-Jul-83	1220	41.5/P	37.45		1.97		1.11					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-2B-4	09-Jul-83	1235	P		RL				9.10	45.90	573.10	17.90	8.20
D-2-3	09-Jul-83	1415	P		LR				877.70	76.10	205.20	56.00	39.27
D-2-3	09-Jul-83	1430	P			3.86		1.08					
D-2-3	09-Jul-83	1440	P				14.6						
D-2-3	09-Jul-83	1445	P				14.6						
D-2-4	09-Jul-83	1515	P		LR				304.57	170.25	54.47	46.73	26.00
D-2-4	09-Jul-83	1530	P				14.6						
D-2-4	09-Jul-83	1545	P				14.6						
D-2-4	09-Jul-83	1600	P				14.6						
D-2-4	09-Jul-83	1610	P			3.84		1.08					
D-2-5	09-Jul-83	1615	P		RL		14.6		422.67	76.80	229.67	195.25	287.00
D-2-5	09-Jul-83	1630	P				14.6						
D-2-5	09-Jul-83	1645	P				14.6						
D-2-5	09-Jul-83	1700	P				16.3						
D-2-6	09-Jul-83	1715	P		LR		14.6		401.33	339.30	421.20	457.20	605.33

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-2-6	09-Jul-83	1730	P				14.6						
D-2-6	09-Jul-83	720	P			4.94		0.06					
D-3-1	10-Jul-83	730			LR		13.6		12150.00	1142.00	46560.00	824.00	1002.00
D-3-1	10-Jul-83	750					13.6						
D-3-1	10-Jul-83	820				4.95	13.6	0.52					
D-3-2	10-Jul-83	835			LR		13.6		902.00	831.33	39.59	1078.67	100.43
D-3-2	10-Jul-83	840	50.0	47.00									
D-3-2	10-Jul-83	845					13.6						
D-3-2	10-Jul-83	910					14.4						
D-3-2	10-Jul-83	915					13.6						
D-3-2	10-Jul-83	920	50.0	47.10		4.94		0.51					
D-3-3	10-Jul-83	930			RL				687.20	13.22	118.60	707.20	
D-3-3	10-Jul-83	945					14.4						
D-3-3	10-Jul-83	1000					13.6						
D-3-3	10-Jul-83	1030			RL		13.6		352.25		2567.27	101.26	

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-3-4	10-Jul-83	1045					13.6						
D-3-4	10-Jul-83	1100					14.4						
D-3-4	10-Jul-83	1210	45.0	41.20									
D-3-4	10-Jul-83	1230					13.6						
D-3-5	10-Jul-83	1245					13.6						
D-3-4	10-Jul-83	1300			RL	4.98	13.6	0.89	14.14	9.63	157.21	2588.57	145.77
D-3-5	10-Jul-83	1315					13.6						
D-3-5	10-Jul-83	1330					13.6						
D-3-5	10-Jul-83	1345	42.0	37.98		3.99	13.6	0.40					
D-3-6	10-Jul-83	1400			RL		13.6		1964.55	672.00		168.68	
D-3-6	10-Jul-83	1415	41.0	36.90									
D-3-6	10-Jul-83	1420					13.6						
D-3-6	10-Jul-83	1430				5.00		0.65					
D-3-6	10-Jul-83	1435				0.00	13.6	0.76					
D-3-6	10-Jul-83	1440	41.0	36.90									
D-3-7	10-Jul-83	1500			LR		13.6			191.22		1128.67	

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-3-7	10-Jul-83	1510	40.0	35.90									
D-3-7	10-Jul-83	600				4.91		0.80					
D-4-1	13-Jul-83	630	P		RL				267.50	62.80	33.60	63.40	71.20
D-4-1	13-Jul-83	645	39.0/P	34.85									
D-4-1	13-Jul-83	715	39.0	34.85		4.89		0.99					
D-4-2	13-Jul-83	730	P		LR		13.3		231.20	96.90	93.20	99.10	507.20
D-4-2	13-Jul-83	745	P			4.91	13.3	0.80					
D-4-2	13-Jul-83	800	P				13.3						
D-4-2	13-Jul-83	810	P				13.3						
D-4-2	13-Jul-83	825	43.0/P	39.05		4.92	13.3	0.74					
D-4-3	13-Jul-83	830	P		LR		13.3		247.80	137.20	179.50	155.40	1698.50
D-4-3	13-Jul-83	915	P				14.1						
D-4-4	13-Jul-83	930	P		RL		14.1		914.80	413.20	452.40	145.70	765.40
D-4-4	13-Jul-83	945	47.0/P	43.52			14.1						
D-4-4	13-Jul-83	1000	P			4.98	14.1	0.79					
D-4-4	13-Jul-83	1015	P				13.3						

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-4-4	13-Jul-83	1020	48.0/P	44.69		4.90		1.16					
D-4-5	13-Jul-83	1030	P		RL		13.3		675.80	858.60	551.60	431.80	818.80
D-4-5	13-Jul-83	1040	P			0.00		0.94					
D-4-5	13-Jul-83	1045	48.0/P	44.69									
D-4-5	13-Jul-83	1100	P				13.3						
D-4-5	13-Jul-83	1120	48.0/P	44.69		4.97	13.3	0.90					
D-4-6	13-Jul-83	1125	P		RL				224.80	403.40	625.20	780.40	546.60
D-4-6	13-Jul-83	1215	49.0/P	45.88		4.97	14.1	0.88					
D-4-7	13-Jul-83	1230	P		LR		14.1		848.20	75.10	109.80	67.50	133.40
D-4-7	13-Jul-83	1245	48.0/P	44.69		0.00	14.1	0.75					
D-4-7	13-Jul-83	1300	P				14.1						
D-4-7	13-Jul-83	1325	48.0/P	44.69		4.98		0.78					
D-4-8	13-Jul-83	1330			LR		14.1		548.08	10.87	64.60	16.40	287.40
D-4-8	13-Jul-83	1415					14.1						
D-4-8	13-Jul-83	1420	46.0	42.38		4.95		0.70					
D-4-9	13-Jul-83	1430			RL		14.1		55.70	38.20	31.80	347.40	14.87

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-4-9	13-Jul-83	1435				0.00		1.34					
D-4-9	13-Jul-83	1445	47.0	43.52			14.1						
D-4-9	13-Jul-83	1530	46.0	42.38		0.00	14.1	1.11					
D-4-9	13-Jul-83	1545	46.0	42.38									
D-5-1	14-Jul-83	900			RL	4.96	12.8	0.00	173.40	258.00	126.20	72.30	455.60
D-5-1	14-Jul-83	920					13.5						
D-5-1	14-Jul-83	920					13.5						
D-5-2	14-Jul-83	1010			LR				345.00	250.80	138.80	235.80	166.80
D-5-2	14-Jul-83	1015					13.5						
D-5-2	14-Jul-83	1030	48.0	44.69		0.00		0.84					
D-5-2	14-Jul-83	1045	47.0	43.52		5.04		1.08					
D-5-3	14-Jul-83	1100	P		LR		13.5		255.40	225.20	187.60	171.40	149.40
D-5-3	14-Jul-83	1130	48.0/P	44.69		0.00		0.68					
D-5-4	14-Jul-83	1230	51.0/P	48.35	RL				56.40	102.00	108.70	115.90	105.30
D-5-5	14-Jul-83	1300	P		LR		13.5		235.20	97.70	106.50	153.60	235.40
D-5-5	14-Jul-83	1315	P			0.00	13.5	1.12					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-5-5	14-Jul-83	1335	48.0/P	44.69		0.00		0.60					
D-5-5	14-Jul-83	1345	P				12.8						
D-5-6	14-Jul-83	1400	P		RL		13.5		188.20	72.00	44.70	26.80	104.70
D-5-6	14-Jul-83	1405	48.0/P	44.69									
D-5-6	14-Jul-83	1430	P				13.5						
D-5-6	14-Jul-83	1440	P			0.00		0.80					
D-5-6	14-Jul-83	1445	P				12.8						
D-5-6	14-Jul-83	1500	P				13.5						
D-5-7	14-Jul-83	1505	P		RL				85.60	32.70	118.80	22.80	572.94
D-5-7	14-Jul-83	1530	P				13.5						
D-5-7	14-Jul-83	1545	P				12.8						
D-5-8	14-Jul-83	1600	P				12.8		67.00	25.40	97.80	65.10	58.30
D-5-9	14-Jul-83	1645	43.0/P	39.05	LR	0.00	12.8	0.74	1461.33	71.60	81.60	106.10	255.80
D-6-1	24-Jul-83	700	42.5		LR	3.67	17.3	0.36	207.90	119.00	363.20	90.50	49.32
D-6-1	24-Jul-83	715	44.0		LR	3.61	17.3	0.83					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-5-5	14-Jul-83	1335	48.0/P	44.69		0.00		0.60					
D-5-5	14-Jul-83	1345	P				12.8						
D-5-6	14-Jul-83	1400	P		RL		13.5		188.20	72.00	44.70	26.80	104.70
D-5-6	14-Jul-83	1405	48.0/P	44.69									
D-5-6	14-Jul-83	1430	P				13.5						
D-5-6	14-Jul-83	1440	P			0.00		0.80					
D-5-6	14-Jul-83	1445	P				12.8						
D-5-6	14-Jul-83	1500	P				13.5						
D-5-7	14-Jul-83	1505	P		RL				85.60	32.70	118.80	22.80	572.94
D-5-7	14-Jul-83	1530	P				13.5						
D-5-7	14-Jul-83	1545	P				12.8						
D-5-8	14-Jul-83	1600	P				12.8		67.00	25.40	97.80	65.10	58.30
D-5-9	14-Jul-83	1645	43.0/P	39.05	LR	0.00	12.8	0.74	1461.33	71.60	81.60	106.10	255.80
D-6-1	24-Jul-83	700	42.5		LR	3.67	17.3	0.36	207.90	119.00	363.20	90.50	49.32
D-6-1	24-Jul-83	715	44.0		LR	3.61	17.3	0.83					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-6-1	24-Jul-83	745	45.0			3.44	17.3	0.00					
D-6-2	24-Jul-83	800			RL	0.00	17.3	0.33	223.50	73.60	16.49	144.00	393.20
D-6-2	24-Jul-83	815	45.0			3.44	17.3	0.38					
D-6-2	24-Jul-83	845					15.4						
D-6-2	24-Jul-83	850	45.0			3.44		0.36					
D-6-2	24-Jul-83	905					19.2						
D-6-3	24-Jul-83	915	45.0		LR	3.44	17.3	0.24	71.76	108.50	11.15	91.30	44.70
D-6-3	24-Jul-83	930					16.2						
D-6-3	24-Jul-83	945					18.0						
D-6-3	24-Jul-83	950	45.0			3.44		0.25					
D-6-4	24-Jul-83	1000			LR		14.5		14.81		28006.00	94.20	21.29
D-6-4	24-Jul-83	1015	44.0				18.0						
D-6-4	24-Jul-83	1030					16.2						
D-6-4	24-Jul-83	1045	44.0				14.5						
D-6-5	24-Jul-83	1145			LR				1106.70	115.80	32.17	61.90	975.30
D-6-5	24-Jul-83	1200	41.0			3.67	16.2	0.36					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-6-5	24-Jul-83	1215	41.0			3.67		0.37					
D-6-6	24-Jul-83	1235			RL		16.2		417.30	251.80	12800.00	243.70	204.60
D-6-6	24-Jul-83	1245	40.0			3.59		0.74					
D-6-6	24-Jul-83	1315	35.0			0.00		0.92					
D-6-7	24-Jul-83	1330			LR		16.2		1036.20	149.70	456.70	409.50	145.30
D-6-7	24-Jul-83	1345	36.0			3.59		0.76					
D-6-7	24-Jul-83	1415	36.0			0.00	16.2	0.50					
D-6-8	24-Jul-83	1430			LR		16.5			693.20	15740.00	524.50	99.60
D-6-8	24-Jul-83	1445				14.5							
D-6-8	24-Jul-83	1500	36.0		3.59	14.5	0.41						
D-7-1	25-Jul-83	700			LR		16.2		3445.40	195.10	3824.40	1185.90	106.60
D-7-1	25-Jul-83	715	44.0			3.56	13.7	0.36					
D-7-1	25-Jul-83	730					13.7						
D-7-1	25-Jul-83	745	45.0										
D-7-1	25-Jul-83	750					16.2						

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-7-2	25-Jul-83	800			RL		13.7		346.90	417.00	83130.00	161.40	518.50
D-7-2	25-Jul-83	815				0.00		0.41					
D-7-3	25-Jul-83	900			LR		14.5		3970.00	233.80	2290.00	604.40	748.10
D-7-3	25-Jul-83	915	45.0			3.44	14.5	0.31					
D-7-3	25-Jul-83	930					13.7						
D-7-3	25-Jul-83	945	45.0			0.00	16.2	0.31					
D-7-4	25-Jul-83	1000			RL		16.2		45890.00	103.20	535.50	180.80	91.50
D-7-4	25-Jul-83	1015	43.0			3.44	16.2	0.41					
D-7-4	25-Jul-83	1030					14.5						
D-7-4	25-Jul-83	1045					15.4						
D-7-5	25-Jul-83	1100	43.0		LR		16.5		288.00	127.70	8664.00	209.20	187.80
D-7-5	25-Jul-83	1115					18.6						
D-7-5	25-Jul-83	1145	42.0			0.00		0.41					
D-7-6	25-Jul-83	1200			RL					179.40	1574.10	280.90	371.70
D-7-6	25-Jul-83	1230					14.5						
D-7-6	25-Jul-83	1245	40.5			3.59	17.3	0.41					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-7-7	25-Jul-83	1300			LR		15.4			479.70	30900.00	458.20	603.00
D-7-7	25-Jul-83	1315	40.0			0.00	15.4	0.31					
D-7-7	25-Jul-83	1330					17.3						
D-7-7	25-Jul-83	1345	37.0			0.00	14.5	0.54					
D-7-8	25-Jul-83	1400			RL		13.7			448.80	83510.00	2090.60	225.30
D-7-8	25-Jul-83	1430					16.5						
D-7-8	25-Jul-83	1445	37.0			0.00	16.5	0.56					
D-7-9	25-Jul-83	1500			LR					203.80	27980.00	225.30	485.40
D-8-1	26-Jul-83	700	46.0		LR	3.61		0.64	342.90	81.90	187.20	1123.30	47.90
D-8-1	26-Jul-83	715				1.97	17.5	0.33					
D-8-1	26-Jul-83	730					17.5						
D-8-1	26-Jul-83	845	50.0			0.00		0.55					
D-8-2	26-Jul-83	900			RL		15.8		125.30	86.40	110.60	48.40	45.50
D-8-2	26-Jul-83	915					17.5						
D-8-2	26-Jul-83	930				0.98	15.8	0.70					

(Continued)

Appendix H. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-8-2	26-Jul-83	945	50.0			0.00	15.8	0.49					
D-8-3	26-Jul-83	1000			LR		15.8		56.00	58.90	98.80	36.90	47.10
D-8-3	26-Jul-83	1015	50.0			0.98	15.8	0.52					
D-8-3	26-Jul-83	1030					15.8						
D-8-3	26-Jul-83	1045	49.0			0.98	17.5	0.51					
D-8-4	26-Jul-83	1100			RL		17.5		111.80	36.20	19.20	15.10	14.50
D-8-4	26-Jul-83	1115	48.5			1.97		0.50					
D-8-4	26-Jul-83	1125					15.8						
D-8-4	26-Jul-83	1135					17.5						
D-8-4	26-Jul-83	1145	48.0			1.97		1.31					
D-8-4	26-Jul-83	1215	48.0			1.97		0.42					
D-8-5	26-Jul-83	1220			LR				58.60	16.30	77.80	40.70	41.60
D-8-5	26-Jul-83	1245	47.0			1.97	15.8	0.52					
D-8-6	26-Jul-83	1300			LR		14.0			22.50	215.00	53.30	228.50
D-8-6	26-Jul-83	1315	46.0			1.97	14.0	0.39					
D-8-6	26-Jul-83	1330					15.8						

(Continued)

Appendix H. (Concluded)

Sample Number	Date (dy/mo/yr)	Time	Dredging Depth/ Cut Type*	Ladder Angle (decimal degrees)	Swing Direction	Cutter Speed (fps)	Suction Intake Velocity (fps)	Swing Speed (fps)	Total Suspended Sediment (mg/ℓ) Sampling Tube 1	2	3	4	5
D-8-6	26-Jul-83	1345					15.8						
D-8-7	26-Jul-83	1400					14.0		33.70	56.70	152.70	91.00	93.00
D-8-7	26-Jul-83	1415	45.0		LR	1.95	15.8	0.30					
D-8-8	26-Jul-83	1500	44.0		LR	1.97	15.8	0.31	1193.80	31.00	81.40	44.10	74.80

Appendix I
Background Concentrations at Calumet Harbor, 1985

Appendix I. Background Concentrations at Calumet Harbor, 1985

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2101.01	21-Oct-85	1210	100	1.7	1	4
2101.11	21-Oct-85	1315	100	1.8	1	4
2102.01	21-Oct-85	1155	100	2	1	1
2102.11	21-Oct-85	1326	100	2	1	1
2103.01	21-Oct-85	1205	100	2	1	2
2103.11	21-Oct-85	1332	100	2	1	2
2104.01	21-Oct-85	1215	100	3	1	3
2104.11	21-Oct-85	1338	100	1.5	1	3
2105.01	21-Oct-85	1220	200	1.6	1	4
2105.11	21-Oct-85	1325	200	1.5	1	4
2106.01	21-Oct-85	1228	200	2	1	1
2106.11	21-Oct-85	1345	200	1.5	1	1
2107.01	21-Oct-85	1237	200	2	1	2
2107.11	21-Oct-85	1351	200	2	1	2
2108.01	21-Oct-85	1245	400	1.4	1	4
2108.11	21-Oct-85	1331	400	1.1	1	4
2109.01	21-Oct-85	1250	800	1.4	1	4
2109.11	21-Oct-85	1350	800	1.5	1	4
2110.01	21-Oct-85	1247	400	2	1	1
2110.11	21-Oct-85	1357	400	2	1	1

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2201.01	22-Oct-85	1424	100	1.5	1	4
2201.11	22-Oct-85	1140	100	1.5	1	4
2201.11	22-Oct-85	1501	100	2	1	4
2202.01	22-Oct-85	1035	100	2	1	1
2202.01	22-Oct-85	1423	100	2	1	1
2202.11	22-Oct-85	1145	100	2	1	1
2202.11	22-Oct-85	1509	100	2	1	1
2203.01	22-Oct-85	1040	100	2	1	2
2203.01	22-Oct-85	1432	100	2	1	2
2203.11	22-Oct-85	1154	100	2	1	2
2203.11	22-Oct-85	1514	100	2	1	2
2204.01	22-Oct-85	1045	100	2	1	3
2204.01	22-Oct-85	1426	100	2	1	3
2204.11	22-Oct-85	1149	100	2	1	3
2204.11	22-Oct-85	1505	100	2	1	3
2205.01	22-Oct-85	1037	200	1.5	1	4
2205.01	22-Oct-85	1427	200	1.5	1	4
2205.11	22-Oct-85	1145	200	1.5	1	4
2205.11	22-Oct-85	1505	200	1.4	1	4
2206.01	22-Oct-85	1051	200	2	1	1
2206.01	22-Oct-85	1440	200	2	1	1

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2206.11	22-Oct-85	1203	200	2	1	1
2206.11	22-Oct-85	1523	200	2	1	1
2207.01	22-Oct-85	1056	200	2	1	2
2207.01	22-Oct-85	1436	200	2	1	2
2207.11	22-Oct-85	1159	200	2	1	2
2207.11	22-Oct-85	1518	200	2	1	2
2208.01	22-Oct-85	1044	400	1.5	1	4
2208.01	22-Oct-85	1435	400	1.3	1	4
2208.11	22-Oct-85	1154	400	1.5	1	4
2208.11	22-Oct-85	1512	400	1.4	1	4
2209.01	22-Oct-85	1053	800	2	1	4
2209.01	22-Oct-85	1445	800	1.6	1	4
2209.11	22-Oct-85	1204	800	1.5	1	4
2209.11	22-Oct-85	1522	800	2	1	4
2210.01	22-Oct-85	1100	400	2	1	1
2210.01	22-Oct-85	1445	400	2	1	1
2210.11	22-Oct-85	1207	400	2	1	1
2210.11	22-Oct-85	1529	400	2	1	1
2101.02	21-Oct-85	1210	100	16.5	2	4
2101.12	21-Oct-85	1315	100	17.5	2	4
2102.02	21-Oct-85	1155	100	17.5	2	1

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2102.12	21-Oct-85	1326	100	17	2	1
2103.02	21-Oct-85	1205	100	19.5	2	2
2103.12	21-Oct-85	1332	100	19	2	2
2104.02	21-Oct-85	1215	100	17	2	3
2104.12	21-Oct-85	1338	100	16	2	3
2105.02	21-Oct-85	1220	200	16	2	4
2105.12	21-Oct-85	1325	200	15.3	2	4
2106.02	21-Oct-85	1228	200	17	2	1
2106.12	21-Oct-85	1345	200	16.5	2	1
2107.02	21-Oct-85	1237	200	18.5	2	2
2107.12	21-Oct-85	1351	200	18.5	2	2
2108.02	21-Oct-85	1245	400	12.5	2	4
2108.12	21-Oct-85	1331	400	11	2	4
2109.02	21-Oct-85	1250	800	14	2	4
2109.12	21-Oct-85	1350	800	15	2	4
2110.02	21-Oct-85	1247	400	19.5	2	1
2110.12	21-Oct-85	1357	400	19.5	2	1
2201.02	22-Oct-85	1424	100	15	2	4
2201.12	22-Oct-85	1140	100	15	2	4
2201.12	22-Oct-85	1501	100	15	2	4

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2202.02	22-Oct-85	1035	100	16.5	2	1
2202.02	22-Oct-85	1423	100	16	2	1
2202.12	22-Oct-85	1145	100	16	2	1
2202.12	22-Oct-85	1509	100	16	2	1
2203.02	22-Oct-85	1040	100	17	2	2
2203.02	22-Oct-85	1432	100	19	2	2
2203.12	22-Oct-85	1154	100	18.5	2	2
2203.12	22-Oct-85	1514	100	18.5	2	2
2204.02	22-Oct-85	1045	100	18.5	2	3
2204.02	22-Oct-85	1426	100	18.5	2	3
2204.12	22-Oct-85	1149	100	17.5	2	3
2204.12	22-Oct-85	1505	100	17	2	3
2205.02	22-Oct-85	1037	200	15.5	2	4
2205.02	22-Oct-85	1427	200	15	2	4
2205.12	22-Oct-85	1145	200	15	2	4
2205.12	22-Oct-85	1505	200	14	2	4
2206.02	22-Oct-85	1051	200	17	2	1
2206.02	22-Oct-85	1440	200	17	2	1
2206.12	22-Oct-85	1203	200	18	2	1
2206.12	22-Oct-85	1523	200	17	2	1
2207.02	22-Oct-85	1056	200	19	2	2
2207.02	22-Oct-85	1436	200	18	2	2

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2207.12	22-Oct-85	1159	200	18	2	2
2207.12	22-Oct-85	1518	200	19	2	2
2208.02	22-Oct-85	1044	400	15	2	4
2208.02	22-Oct-85	1435	400	13	2	4
2208.12	22-Oct-85	1154	400	14.5	2	4
2208.12	22-Oct-85	1512	400	13.5	2	4
2209.02	22-Oct-85	1053	800	16	2	4
2209.02	22-Oct-85	1445	800	15.5	2	4
2209.12	22-Oct-85	1204	800	14.5	2	4
2209.12	22-Oct-85	1522	800	18	2	4
2210.02	22-Oct-85	1100	400	19.5	2	1
2210.02	22-Oct-85	1445	400	20	2	1
2210.12	22-Oct-85	1207	400	20	2	1
2210.12	22-Oct-85	1529	400	20	2	1
2101.03	21-Oct-85	1210	100	28.1	3	4
2101.13	21-Oct-85	1315	100	30.2	3	4
2102.03	21-Oct-85	1155	100	30	3	1
2102.13	21-Oct-85	1326	100	29	3	1
2103.03	21-Oct-85	1205	100	33	3	2
2103.13	21-Oct-85	1332	100	32	3	2
2104.03	21-Oct-85	1215	100	20	3	3
2104.13	21-Oct-85	1338	100	27.5	3	3
2105.03	21-Oct-85	1220	200	27.2	3	4

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2105.03	21-Oct-85	1220	200	27.2	3	4
2105.13	21-Oct-85	1325	200	25.9	3	4
2106.03	21-Oct-85	1228	200	29	3	1
2106.13	21-Oct-85	1345	200	28	3	1
2107.03	21-Oct-85	1237	200	31.5	3	2
2107.13	21-Oct-85	1351	200	31.5	3	2
2108.03	21-Oct-85	1245	400	21.3	3	4
2108.13	21-Oct-85	1331	400	18.7	3	4
2109.03	21-Oct-85	1250	800	23.8	3	4
2109.13	21-Oct-85	1350	800	25.5	3	4
2110.03	21-Oct-85	1247	400	33	3	1
2110.13	21-Oct-85	1357	400	33	3	1
2201.03	22-Oct-85	1424	100	25.5	3	4
2201.13	22-Oct-85	1140	100	25.5	3	4
2201.13	22-Oct-85	1501	100	25	3	4
2202.03	22-Oct-85	1035	100	28	3	1
2202.03	22-Oct-85	1423	100	27	3	1
2202.13	22-Oct-85	1145	100	27	3	1
2202.13	22-Oct-85	1509	100	27.5	3	1
2203.03	22-Oct-85	1040	100	29	3	2

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2203.03	22-Oct-85	1432	100	32	3	2
2203.13	22-Oct-85	1154	100	31.5	3	2
2203.13	22-Oct-85	1514	100	31.5	3	2
2204.03	22-Oct-85	1045	100	31.5	3	3
2204.03	22-Oct-85	1426	100	31.5	3	3
2204.13	22-Oct-85	1149	100	30	3	3
2204.13	22-Oct-85	1505	100	29	3	3
2205.03	22-Oct-85	1037	100	24.7	3	4
2205.03	22-Oct-85	1427	200	25.5	3	4
2205.13	22-Oct-85	1145	200	25.5	3	4
2205.13	22-Oct-85	1505	200	23.8	3	4
2206.03	22-Oct-85	1051	200	29	3	1
2206.03	22-Oct-85	1440	200	29	3	1
2206.13	22-Oct-85	1203	200	30.5	3	1
2206.13	22-Oct-85	1523	200	29	3	1
2207.03	22-Oct-85	1056	200	32	3	2
2207.03	22-Oct-85	1436	200	30.5	3	2
2207.13	22-Oct-85	1159	200	30.5	3	2
2207.13	22-Oct-85	1518	200	32.5	3	2
2208.03	22-Oct-85	1044	400	25.5	3	4
2208.03	22-Oct-85	1435	400	22.1	3	4

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2208.13	22-Oct-85	1154	400	24.7	3	4
2208.13	22-Oct-85	1512	400	23	3	4
2209.03	22-Oct-85	1053	800	25	3	4
2209.03	22-Oct-85	1445	800	26.4	3	4
2209.13	22-Oct-85	1204	800	24.5	3	4
2209.13	22-Oct-85	1522	800	30	3	4
2210.03	22-Oct-85	1100	400	33	3	1
2210.03	22-Oct-85	1445	400	32	3	1
2210.13	22-Oct-85	1207	400	32	3	1
2210.13	22-Oct-85	1529	400	32	3	1
2101.04	21-Oct-85	1210	100	31.4	4	4
2101.14	21-Oct-85	1315	100	33.7	4	4
2102.04	21-Oct-85	1155	100	34	4	1
2102.14	21-Oct-85	1326	100	32	4	1
2103.04	21-Oct-85	1205	100	37	4	2
2103.14	21-Oct-85	1332	100	36	4	2
2104.04	21-Oct-85	1215	100	28.5	4	3
2104.14	21-Oct-85	1338	100	31	4	3
2105.04	21-Oct-85	1220	200	28	4	4
2105.14	21-Oct-85	1325	200	29	4	4
2106.04	21-Oct-85	1228	200	32.5	4	1
2106.14	21-Oct-85	1345	200	31.5	4	1

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2107.04	21-Oct-85	1237	200	35	4	2
2107.14	21-Oct-85	1351	200	35	4	2
2108.04	21-Oct-85	1245	400	23.8	4	4
2108.14	21-Oct-85	1331	400	20.9	4	4
2109.04	21-Oct-85	1250	800	24.6	4	4
2109.14	21-Oct-85	1350	800	29	4	4
2110.04	21-Oct-85	1247	400	37	4	1
2110.14	21-Oct-85	1357	400	37	4	1
2201.04	22-Oct-85	1424	100	29.5	4	4
2201.14	22-Oct-85	1140	100	28.5	4	4
2201.14	22-Oct-85	1501	100	28	4	4
2202.04	22-Oct-85	1035	100	31.5	4	1
2202.04	22-Oct-85	1423	100	30.5	4	1
2202.14	22-Oct-85	1145	100	30.5	4	1
2202.14	22-Oct-85	1509	100	31	4	1
2203.04	22-Oct-85	1040	100	32	4	2
2203.04	22-Oct-85	1432	100	36	4	2
2203.14	22-Oct-85	1154	100	35	4	2
2203.14	22-Oct-85	1514	100	35	4	2
2204.04	22-Oct-85	1045	100	35	4	3

(Continued)

Appendix I. (Continued)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2204.04	22-Oct-85	1426	100	35	4	3
2204.14	22-Oct-85	1149	100	33	4	3
2204.14	22-Oct-85	1505	100	32	4	3
2205.04	22-Oct-85	1037	200	27.6	4	4
2205.04	22-Oct-85	1427	200	28.5	4	4
2205.14	22-Oct-85	1145	200	28.5	4	4
2205.14	22-Oct-85	1505	200	26.6	4	4
2206.04	22-Oct-85	1051	200	32	4	1
2206.04	22-Oct-85	1440	200	32	4	1
2206.14	22-Oct-85	1203	200	34	4	1
2206.14	22-Oct-85	1523	200	32	4	1
2207.04	22-Oct-85	1056	200	36	4	2
2207.04	22-Oct-85	1436	200	34	4	2
2207.14	22-Oct-85	1159	200	34	4	2
2207.14	22-Oct-85	1518	200	36	4	2
2208.04	22-Oct-85	1044	400	28.2	4	4
2208.04	22-Oct-85	1435	400	24.7	4	4
2208.14	22-Oct-85	1154	400	27.6	4	4
2208.14	22-Oct-85	1512	400	24.5	4	4
2209.04	22-Oct-85	1053	800	28	4	4
2209.04	22-Oct-85	1445	800	29.5	4	4
2209.14	22-Oct-85	1204	800	27.6	4	4

(Continued)

Appendix I. (Concluded)

Sample Number	Date (dy/mo/yr)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Station Number	Total Suspended Sediment (mg/ℓ)
2209.14	22-Oct-85	1522	800	33	4	4
2210.04	22-Oct-85	1100	400	37	4	1
2210.04	22-Oct-85	1445	400	38	4	1
2210.14	22-Oct-85	1207	400	38	4	1
2210.14	22-Oct-85	1529	400	38	4	1

Appendix J
Matchbox Suction Dredge Operating Characteristics at Calumet Harbor, 1985

Appendix J. Matchbox Suction Dredge Operating Characteristics at Calumet Harbor, 1985

Date	Time	Flow gal/min	Production cu yd/hr	Depth ft	Swing Speed ft/sec
Oct 21	1025	6130	28	31	0.6
Oct 21	1040	5575	74	31	0.6
Oct 21	1055	3800	83	31	0.6
Oct 21	1110	5400	70	31	0.6
Oct 21	1125	5400	65	31	0.6
Oct 21	1140	6400	45	31	0.6
Oct 21	1155	3900	66	31	0.6
Oct 21	1210	4000	67	31	0.6
Oct 21	1225	4850	62	31	0.6
Oct 21	1240	4000	74	31	0.6
Oct 21	1255	5650	48	31	0.6
Oct 21	1310	6140	50	31	0.6
Oct 21	1325	4160	57	31	0.6
Oct 21	1340	3400	59	31	0.6
Oct 21	1355	4800	64	31	0.6
Oct 21	1410	6460	30	31	0.6
Oct 22	940	5900	27.5	31	1.6
Oct 22	955	4300	32.5	31	1.6
Oct 22	1010	6200	31.2	31	1.6
Oct 22	1025	6150	34.7	31	1.6
Oct 22	1040	6660	34.3	31	1.6

(Continued)

Appendix J. (Concluded)

Date	Time	Flow gal/min	Production cu yd/hr	Depth ft	Swing Speed ft/sec
Oct 22	1055	3500	59.5	31	1.6
Oct 22	1110	4190	68.6	31	1.6
Oct 22	1125	5650	46.1	31	1.6
Oct 22	1140	5950	46	31	1.6
Oct 22	1155	3750	67	31	0.5
Oct 22	1210	5600	35	31	0.5
Oct 22	1335	5600	49.2	31	0.5
Oct 22	1350	2700	63	31	0.5
Oct 22	1405	5600	38.2	31	0.5
Oct 22	1420	4100	60	31	0.5
Oct 22	1435	5900	41	31	0.5
Oct 22	1450	5450	51	31	0.5
Oct 22	1505	5400	48.5	31	0.5
Oct 22	1520	5700	53	31	0.5

Appendix K
Matchbox Suction Dredge Concentrations at Calumet Harbor, 1985

Appendix K. Matchbox Suction Dredge Concentrations at Calumet Harbor, 1985

Sample Number	Date (dy/mo/yr)	Time	Swing Speed (fps)	Swing Direction (E: Left to Right R: Right to Left	Total Supsended Sediment (mg/ℓ) Tube 1	Tube 2	Tube 3	Tube 4	Tube 5	Tube 6
211025	21-Oct-85	1025	0.6	R	11	33	132180			
	21-Oct-85	1025	0.6	R				635	290	38
211055	21-Oct-85	1055	0.6	L	814	50	120			
	21-Oct-85	1055	0.6	R				65	40	39
	21-Oct-85	1125	0.6	R	12	28	46	28	17	11
211155	21-Oct-85	1155	0.6	L	2700	81	211	39	32	28
	21-Oct-85	1225	0.6	R	41	17	26	84	6	13
211255	21-Oct-85	1255	0.6	L	12	8	22	28	22	46
211325	21-Oct-85	1325	0.6	R	21	12	18	10	19	15
211355	21-Oct-85	1355	0.6	L	11	7	13	8	11	
211410	21-Oct-85	1410	0.6	L	18	22	31	8	5	8
220935	22-Oct-85	935		R	3	11	9	12	12	11
	22-Oct-85	940	1.6	L						
221010	22-Oct-85	1010	1.6	R	7	13	19	20	35	22
	22-Oct-85	1040	1.6	R	1310	2600	7000	4800	13500	37000

(Continued)

Appendix K. (Concluded)

Sample Number	Date (dy/mo/yr)	Time	Swing Speed (fps)	Swing Direction (E: Left to Right R: Right to Left	Total Supsended Sediment (mg/ℓ) Tube 1	Tube 2	Tube 3	Tube 4	Tube 5	Tube 6
221110	22-Oct-85	1110	1.6	R	63	155	413	1140	3460	119000
221140	22-Oct-85	1140	1.6	L	3920	1144	1080	1400	764	83000
221210	22-Oct-85	1210	0.5	L	1600	2600	4900	3000	1790	2770
221330	22-Oct-85	1335	0.5	L	1330	2200	17664	27000	696	64
221350	22-Oct-85	1350	0.5	R	66	760	233	270	1720	2440
221410	22-Oct-85	1415	0.5	L	66	80	80	22	1300	890
221440	22-Oct-85	1440	0.5	R	74	56	26	93	930	94
221515	22-Oct-85	1515	0.5	L	34	26	36	91	91	338

Appendix L
Cutterhead Suction Dredge Operating Characteristics at Calumet Harbor, 1985

Appendix L. Cutterhead Suction Dredge Operating Characteristics at Calumet Harbor, 1985

Date	Time	Flow gpm	Production cu yd/hr	Dredging Depth ft	Swing Speed ft/sec	Cutter Speed RPM
Oct 24	917	5460	30.1	32	0.7	27
Oct 24	930	3400	43.5	32	0.7	27
Oct 24	945	5400	41.5	32	0.7	27
Oct 24	1004	3800	56.5	32	0.7	27
Oct 24	1015	4000	52.5	32	0.7	27
Oct 24	1030	5300	52.1	32	0.7	27
Oct 24	1048	3450	54.5	32	0.7	27
Oct 24	1100	5225	41.1	32	0.7	27
Oct 24	1115	2345	47.8	32	0.7	27
Oct 24	1133	2340	60.1	32	0.7	27
Oct 24	1146	4300	54.0	32	0.7	27
Oct 24	1155	5600	38.6	32	0.7	27
Oct 24	1225	5650	19.3	32	0.7	20
Oct 24	1240	2600	68.0	32	0.7	20
Oct 24	1255	3160	50.3	32	0.7	20
Oct 24	1310	3080	52.5	32	0.7	20
Oct 24	1320	2600	50.8	32	0.7	20
Oct 24	1335	1700	54.0	32	0.7	20
Oct 24	1350	2300	40.5	32	0.7	20
Oct 24	1408	5150	39.5	32	0.7	20
Oct 24	1422	3800	37.6	32	0.7	20
Oct 24	1440	4300	40.6	32	0.7	20

(Continued)

Appendix L. (Continued)

Date	Time	Flow gpm	Production cu yd/hr	Dredging Depth ft	Swing Speed ft/sec	Cutter Speed RPM
Oct 24	1455	2440	26.6	32	0.7	20
Oct 24	1510	1075	41.2	32	0.7	20
Oct 24	1515	4550	38.3	32	0.7	20
Oct 24	1525	1770	37.5	32	0.7	20
Oct 25	855	6030	19.3	31	0.7	15
Oct 25	900	4000	80.1	31	0.7	15
Oct 25	917	3980	71.2	31	0.7	15
Oct 25	930	5175	61.8	31	0.7	15
Oct 25	945	4100	80.1	31	0.7	15
Oct 25	1000	3900	88.7	31	0.7	15
Oct 25	1015	5160	57.3	31	0.7	15
Oct 25	1030	2940	89.8	31	0.7	15
Oct 25	1100	4015	73.1	31	0.7	15
Oct 25	1115	3350	97.1	31	0.7	15
Oct 25	1130	4130	82.5	31	0.7	15
Oct 25	1208	3080	76.1	31	1.1	15
Oct 25	1220	5740	37.3	31	1.1	15
Oct 25	1235	2430	96.1	31	1.1	15
Oct 25	1250	4680	58.8	31	1.1	15
Oct 25	1312	5195	57.9	31	1.1	15
Oct 25	1327	6115	34.7	31	1.1	15

(Continued)

Appendix L. (Continued)

Date	Time	Flow gpm	Production cu yd/hr	Dredging Depth ft	Swing Speed ft/sec	Cutter Speed RPM
Oct 25	1340	6150	35.4	31	1.1	15
Oct 25	1355	3500	89.0	31	1.1	15
Oct 25	1410	4700	60.2	31	1.1	15
Oct 25	1435	2800	101.0	31	1.1	15
Oct 25	1445	2700	81.6	31	1.1	15
Oct 25	1500	2600	90.0	31	1.1	15
Oct 26	842	2125	89.5	29	1.1	27
Oct 26	900	5600	50.5	29	1.1	27
Oct 26	915	5560	65.4	29	1.1	27
Oct 26	930	5350	85.0	29	1.1	27
Oct 26	943	5900	39.0	29	1.1	27
Oct 26	1000	5600	74.0	29	1.1	27
Oct 26	1013	5975	37.0	29	1.1	27
Oct 26	1028	5250	109.0	29	1.1	27
Oct 26	1045	5970	35.0	29	1.1	27
Oct 26	1100	5850	40.8	29	1.1	27
Oct 26	1115	5350	113.0	29	1.1	27
Oct 26	1211	3080	71.5	29	1.1	20
Oct 26	1230	4590	82.3	29	1.1	20
Oct 26	1245	5550	48.3	29	1.1	20
Oct 26	1305	5300	55.0	29	1.1	20

(Continued)

Appendix L. (Concluded)

Date	Time	Flow gpm	Production cu yd/hr	Dredging Depth ft	Swing Speed ft/sec	Cutter Speed RPM
Oct 26	1315	5030	20.5	29	1.1	20
Oct 26	1330	5600	17.0	29	1.1	20
Oct 26	1345	3700	90.0	29	1.1	20
Oct 26	1400	2685	103.0	29	1.1	20
Oct 26	1415	5190	50.0	29	1.1	20
Oct 26	1430	3860	74.0	29	1.1	20
Oct 26	1445	5670	38.0	29	1.1	20

Appendix M
Cutterhead Suction Dredge Concentrations at Calumet Harbor, 1985

Appendix M. Cutterhead Suction Dredge Concentrations at Calumet Harbor, 1985

Date (dy/mo/yr)	Time	Swing Speed (fps)	Cutter Speed (RPM)	Sample Number	Total Suspended Sediment (mg/ℓ) Sampling Tube*					
					1	2	3	4	5	6
Samples Collected During Port to Starboard Swings										
24-Oct-85	937	0.73	27	240935	11	12	4	8	10	10
24-Oct-85	1025	0.73	27	241025	6	9	12	7	9	7
24-Oct-85	1105	0.73	27	241105	10	12	8	12	14	23
24-Oct-85	1150	0.73	27	241150	33	10	6		15	12
24-Oct-85	1245	0.67	20	241245	10	7	4	4	11	2
24-Oct-85	1325	0.67	20	241325	14	22	6	15	8	16
24-Oct-85	1410	0.67	20	241410	20	14	18	12	17	25
24-Oct-85	1500	0.67	20	241500	8	12	7	5	11	20
25-Oct-85	850	0.68	15	250850	4	7	8	5	5	5
25-Oct-85	925	0.68	15	250925	4	6	2	3	3	8
25-Oct-85	1025	0.68	15	251025	11	6	6	6	3	9
25-Oct-85	1110	0.68	15	251110	11	7	7	6	2	3
25-Oct-85	1225	1.10	15	251225	3	4	4	4	8	2
25-Oct-85	1305	1.10	15	251305	14	13	14	13	25	6

(Continued)

Appendix M. (Continued)

Date (dy/mo/yr)	Time	Swing Speed (fps)	Cutter Speed (RPM)	Sample Number	Total Suspended Sediment (mg/ℓ) Sampling Tube* 1	2	3	4	5	6
25-Oct-85	1347	1.10	15	251347	6	8	4	3	4	5
25-Oct-85	1440	1.10	15	251435	25	14	10	12	16	18
26-Oct-85	907	1.12	27	260905	33	13	7	15	10	4
26-Oct-85	945	1.12	27	260926	11	7	5	7	4	7
26-Oct-85	1035	1.12	27	261035	14	14	18		18	10
26-Oct-85	1118	1.12	27	261115	11	9	12		13	7
26-Oct-85	1235	1.15	20	261235	19	16	11	22	12	48
26-Oct-85	1318	1.15	20	261320	10	28	44	28	50	5
26-Oct-85	1405	1.15	20	261400	12	12	15	16	13	7
26-Oct-85	1448	1.15	20	261445	14	15	22	17	23	18
Samples Collected During Starboard to Port Swings										
24-Oct-85	915	0.73	27	240915	9	10	7	17	8	7
24-Oct-85	1000	0.73	27	241000	26	20	11	18	8	8
24-Oct-85	1045	0.73	27	241045	10	19	9	8	5	7
24-Oct-85	1130	0.73	27	241130	10	19	8	7	4	6

(Continued)

Appendix M. (Continued)

Date (dy/mo/yr)	Time	Swing Speed (fps)	Cutter Speed (RPM)	Sample Number	Total Suspended Sediment (mg/ℓ) Sampling Tube* 1	2	3	4	5	6
24-Oct-85	1225	0.67	20	241225	64	11	8	15	17	
24-Oct-85	1305	0.67	20	241305	25	8	12	5	4	4
24-Oct-85	1350	0.67	20	241350	13	11	7	7	8	6
24-Oct-85	1435	0.67	20	241435	14	12	11	15	29	24
24-Oct-85	1520	0.67	20	241520	20	21	15	16	16	22
25-Oct-85	912	0.68	15	250912	6	3	3	3	2	2
25-Oct-85	1000	0.68	15	251000	5	6	4	3	2	3
25-Oct-85	1047	0.68	15	251047	28	17	4	4	16	11
25-Oct-85	1130	0.68	15	251130	12	7	4	4	8	2
25-Oct-85	1205	1.10	15	251205	6	10	8	5	2	6
25-Oct-85	1245	1.10	15	251245	6	61	16	32	18	23
25-Oct-85	1325	1.10	15	251325	18	159	15	27	28	8
25-Oct-85	1410	1.10	15	251410	29	35	8	23	5	13
25-Oct-85	1455	1.10	15	251450	22	40	15	10	19	13
25-Oct-85	847	1.12	27	260845	31	47	10	14	18	7

(Continued)

Appendix M. (Concluded)

Date (dy/mo/yr)	Time	Swing Speed (fps)	Cutter Speed (RPM)	Sample Number	Total Suspended Sediment (mg/ℓ) Sampling Tube* 1	2	3	4	5	6
25-Oct-85	925	1.12	27	260926	33	17	26	40	12	12
25-Oct-85	1005	1.12	27	261005	38	22	12		28	14
25-Oct-85	1055	1.12	27	261055	42	11	10		27	11
25-Oct-85	1215	1.15	20	261215	20	21	20	23	18	6
25-Oct-85	1300	1.15	20	261255	12	11	12	21	30	15
25-Oct-85	1338	1.15	20	261340	14	13	19	12	41	11
25-Oct-85	1425	1.15	20	261425	13	16	11	20	12	88

* Lateral distance in ft of sampling tube from centerline of cutterhead: -7.00 -3.25 -1.00 1.00 3.25 7.00

Appendix N
Hopper Dredge Concentrations Above Background Concentrations at Grays Harbor, November 1983

Appendix N. Hopper Dredge Concentrations Above Background Concentrations at Grays Harbor, November 1983

Operating Mode (N: No overflow Y: overflow)	Distance Downstream of Dredge (ft)	Laterally From Dredge (ft)	Concentrations (mg/ℓ)		
			Near Top	Middepth	Near Bottom
N	0	200	4.30		0.65
N	250	100		0.00	19.56
N	250	200	36.95		6.55
N	500	0	0.00	0.00	1.74
N	500	50		0.00	1.93
N	500	150		0.65	
N	500	300		0.00	0.00
N	750	0	0.35		21.05
N	750	100		0.00	11.98
N	750	200	1.73		6.90
N	1500	0	0.15		30.60
N	1500	50		0.00	0.00
N	1500	100		8.50	23.97
N	1500	300		0.85	0.00
N	2500	0	0.00		29.23
N	2500	100	1.45	0.00	21.75
N	3500	100	0.00	34.00	
N	4500	100			0.00
Y	0	100	0.00	0.00	470.50
Y	0	150	66.20	0.00	29.13

(Continued)

Appendix N. (Continued)

Operating Mode (N: No overflow Y: overflow)	Distance Downstream of Dredge (ft)	Laterally From Dredge (ft)	Concentrations (mg/ℓ) Near Top	Middepth	Near Bottom
Y	250	0	288.34	258.20	687.89
Y	250	100	32.70	0.00	139.40
Y	250	150	57.70		341.28
Y	500	50		131.25	82.40
Y	500	300			14.65
Y	500	400	16.20		16.38
Y	500	400	51.48	547.00	124.33
Y	750	0	5.80	22.06	392.85
Y	750	100	62.90	12.10	92.05
Y	1500	0	4.77	378.65	74.53
Y	1500	50		56.50	69.70
Y	1500	100	13.35	55.23	104.03
Y	1500	150	46.25	1148.20	246.28
Y	1500	400	69.50		174.33
Y	2500	0	3.50	180.50	366.11
Y	2500	50	0.00	19.60	
Y	2500	100	6.95	10.00	134.25
Y	2500	150	34.20	0.70	282.80
Y	2500	400	9.40		21.15
Y	3500	0		33.30	580.90
Y	3500	100	26.70	0.00	50.95

(Continued)

Appendix N. (Concluded)

Operating Mode (N: No overflow Y: overflow)	Distance Downstream of Dredge (ft)	Laterally From Dredge (ft)	Concentrations (mg/ℓ)		
			Near Top	Middepth	Near Bottom
Y	3500	150			0.00
Y	3500	400	69.40		74.70
Y	4500	0		33.45	313.87
Y	4500	150	9.60		1113.15
Y	5500	0	2.10	47.20	119.45
Y	5500	150			452.85
Y	6500	0	0.00	81.45	58.10
Y	7500	0	9.80	0.00	

Appendix O
Background Concentrations at St. Johns River, 1982

Appendix O. Background Concentrations at St. Johns River, 1982

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
9	1400	3500	195	Toward	5	0.2	2	28
10	852	3500	200	Away	5	0	1	8
10	853	3500	200	Away	1	0	0	8
10	1428	3500	200	Toward	1	0	0	20
10	1448	6500	120	Toward	13.1	0	0	32
10	1451	6500	120	Toward	16.4	0	0	112
11	850	3500	185	Away	1	0.3	1.1	40
11	855	3500	185	Away	5	0	0	16
11	900	6500	120	Away	1	0.4	0	20
11	903	6500	120	Away	5	0.1	1.1	16
11	906	6500	120	Away	13.1	0	1.1	52
11	1502	6500	120	Toward	1	0	0	56
11	1505	6500	120	Toward	5	0	0	60
11	1508	6500	120	Toward	9.6	0	2.75	78
11	1510	6500	120	Toward	13.1	0	0	92
11	1520	3500	185	Toward	1	0	0	50
11	1521	3500	185	Toward	5	0.4	2.1	40

Appendix P
Closed-Bucket Clamshell Dredge Concentrations at St. Johns River, 1982

Appendix P. Closed Bucket Clamshell Dredge Concentrations at St. Johns River, 1982

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
9	1420	200	20	5	Away	0.2	0	65
9	1425	200	20	5	Away	0.2	0	80
9	1428	200	20	5	Away	0.2	0	90
9	1430	200	20	5	Away	0.2	0	70
9	1437	200	20	5	Away	0.2	2	140
9	1450	200	20	5	Away	0.1	0	150
9	1458	200	20	10	Away	0.1	0	200
9	1507	200	20	10	Away	0.1	0	200
9	1515	100	15	10	Away	0.0	0	524
9	1525	100	15	5	Away	0	0	286
9	1535	100	15	1	Away	0	2	246
9	1540	400	50	1	Away	0	0	96
9	1543	400	50	5	Away	0	0	116
9	1550	800	45	5	Away	0	0	112

(Continued)

Appendix P. (Continued)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
9	1600	800	45	1	Away	0	2	76
9	1603	800	45	1	Away	0	0	72
11	918	100	200	1	Slack	0	0	20
11	919	100	200	5	Slack	0.1	0	40
11	921	100	200	9.6	Slack	0	0	86
11	922	100	200	13.1	Slack	0	0	84
11	924	100	200	16.4	Slack	0	0	504
11	942	200	240	1	Slack	0	0	25
11	944	200	240	13.1	Slack	0	0	116
11	951	200	240	13.1	Slack	0	0	416
11	1001	200	240	1	Slack	0	0	20
11	1003	200	240	5	Slack	0	0	180
11	1007	200	240	9.6	Slack	0	0	152
11	1010	200	240	13.1	Slack	0	0	496
11	1014	200	240	15	Slack	0	0	488

(Continued)

Appendix P. (Continued)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
11	1018	400	215	1	Slack	0	1.25	36
11	1025	400	215	5	Slack	0	0	44
11	1029	400	215	9.6	Slack	0	0	88
11	1031	400	215	13.1	Slack	0	0	108
11	1037	400	215	15	Slack	0.1	0	148
11	1043	800	215	1	Slack	0	0	80
11	1045	800	215	5	Slack	0	0	116
11	1102	800	150	1	Toward	0	0	68
11	1104	800	150	5	Toward	0	0	144
11	1105	800	150	9.6	Toward	0	0	244
11	1117	400	140	1	Toward	0	0	68
11	1120	400	140	5	Toward	0	0	60
11	1124	400	140	9.6	Toward	0	1.8	80
11	1126	400	140	13.1	Toward	0	0	128
11	1132	400	140	16.4	Toward	0	0	216

(Continued)

Appendix P. (Continued)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
11	1138	200	150	1	Toward	0	0	40
11	1141	200	150	5	Toward	0	0	45
11	1148	200	150	5	Toward	0	0	52
11	1151	200	150	9.6	Toward	0.1	0	92
11	1153	200	150	13.1	Toward	0	0	156
11	1155	200	150	16.4	Toward	0	0	816
11	1205	100	170	1	Toward	0	0	48
11	1207	100	170	5	Toward	0.1	1.9	44
11	1211	100	170	9.6	Toward	0	0	82
11	1212	100	170	9.6	Toward	0	0	108
11	1213	100	170	13.1	Toward	0	0	184
11	1214	100	170	16.4	Toward	0	0	736
11	1330	100	15	3	Away	0	0	156
11	1336	50	15	3	Away	0	0	264
11	1338	50	15	3	Away	0	0	178

Appendix P. (Continued)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
11	1342	50	15	3	Away	0	0	320
11	1343	50	15	1	Away	0	0	130
11	1346	50	15	1	Away	0	0	166
11	1405	50	15	1	Away	0	0	138
11	1407	50	15	3	Away	0	0	128
11	1413	100	30	1	Away	0	0	112
11	1415	100	30	3	Away	0	0	128
11	1418	200	30	1	Away	0	0	114
11	1419	200	30	3	Away	0.2	2	118
11	1425	400	50	1	Away	0	0	114
11	1327	400	50	3	Away	0	0	96
11	1440	800	50	1	Away	0	0	84
11	1445	800	50	3	Away	0.2	0	134
11	1450	800	90	1	Away	0	0	86
11	1452	800	90	5	Away	0	2	82

(Continued)

Appendix P. (Concluded)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
11	1454	800	90	9.6	Away	0	0	90
11	1457	800	90	13.1	Away	0	0	248

Appendix Q
Open-Bucket Clamshell Dredge Concentrations at St. Johns River, 1982

Appendix Q. Open Bucket Clamshell Dredge Concentrations at St Johns River, 1982

				Current				
Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
10	942	50	200	1	Toward	0.2	0	50
10	946	50	200	5	Toward	0.2	0	80
10	948	50	200	13.1	Toward	0.2	0	120
10	955	50	200	5	Toward	0	0	95
10	958	50	200	5	Toward	0	1.25	70
10	1002	50	200	13.1	Toward	0	0	140
10	1004	50	200	16.4	Toward	0	0	136
10	1006	150	200	5	Toward	0	0	115
10	1021	100	200	5	Toward	0	0	592
10	1023	100	200	5	Toward	0	0	135
10	1026	100	200	5	Toward	0	0	135
10	1038	200	205	5	Toward	0.1	0	144
10	1045	200	205	1	Toward	0	0	72
10	1048	200	205	13.1	Toward	0	0	272

(Continued)

Appendix Q. (Continued)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
10	1055	400	205	1	Toward	0	0	56
10	1057	400	205	5	Toward	0.1	0	104
10	1106	800	200	1	Toward	0	0	48
10	1110	800	200	5	Toward	0	0	60
10	1130	800	120	1	Away	0.4	0	52
10	1135	800	120	5	Away	0.1	0	75
10	1140	800	120	9.6	Away	0	1.75	84
10	1146	400	140	1	Away	0	0	44
10	1151	400	140	5	Away	0.07	0	88
10	1155	400	140	9.6	Away	0	0	172
10	1200	400	140	13.1	Away	0	0	250
10	1206	400	140	16.4	Away	0	0	200
10	1212	200	150	1	Away	0	0	52
10	1215	200	150	5	Away	0	0	52
10	1218	200	150	9.6	Away	0.05	0	104

(Continued)

Appendix Q. (Continued)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
10	1220	200	150	13.1	Away	0	0	116
10	1222	200	150	16.4	Away	0	0	215
10	1227	200	150	9.6	Away	0	0	200
10	1300	50	15	1	Away	1.6	1.6	100
10	1306	50	15	3	Away	0	0	180
10	1315	50	15	3	Away	0	0	104
10	1321	50	15	1	Away	0.1	0	232
10	1326	50	15	13.1	Away	0	0	250
10	1330	50	15	16.4	Away	0	0	1880
10	1342	100	15	1	Away	0	0	168
10	1344	100	15	3	Away	0	1.9	312
10	1347	200	15	1	Away	0	0	92
10	1349	200	15	3	Away	0	0	124
10	1353	400	25	1	Away	0	0	86
10	1355	400	25	3	Away	0	0	136

(Continued)

Appendix Q. (Concluded)

Date (February)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Current Direction Relative To Sampling Boat	Sampling Depth (ft)	Current Speed (fps)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
10	1405	800	35	1	Away	0	0	78
10	1410	800	35	3	Away	0	0	112
10	1416	800	100	1	Away	0	2	70
10	1419	800	100	5	Away	0	0	70
10	1420	800	100	9.6	Away	0	0	65
10	1422	800	100	16.4	Away	0	0	70

Appendix R
Background Concentrations at Black Rock Harbor, 1983

Appendix R. Background Concentrations at Black Rock Harbor, 1983

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
2	825	5000	1	220	0.45	101	15.1	29.3
2	825	5000	5	220	0.45	190	19.3	51.3
2	825	5000	10	220	0.28	131	20.3	34.1
2	825	5000	15	220	0.2	165	20	34
2	845	5000	1	220	0.57	239	13.1	22.6
2	845	5000	5	220	0.71	165	19	34.1
2	845	5000	10	220	0.1	135	20.2	55.9
2	845	5000	15	220	0.1	135	20.2	70.8
2	845	5000	20	220	0.14	134	19.9	52.5
2	915	5000	1	30	0.1	100	11	17.6
2	915	5000	5	30	0.3	225	16.4	37.2
2	915	5000	10	30	0.1	265	19.6	91.7
2	915	5000	15	30	0.1	90	20.3	68
2	940	5000	1	30	0.5	79	9	24.2
2	940	5000	5	30	0.2	20	17.2	37.1

(Continued)

Appendix R. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
2	940	5000	10	30	0.22	345	19	56.5
2	940	5000	15	30	0.22	240	20	71.1
2	1130	5000	1	220	0.22	340	15.9	29.6
2	1130	5000	5	220	0.1	350	19	34.7
2	1130	5000	10	220	0.28	291	20.5	32.1
2	1130	5000	15	220	0.2	45	20.5	39.9
2	1200	5000	1	30	0.1	245	8.9	38.9
2	1200	5000	5	30	0.14	324	14.8	32.8
2	1200	5000	10	30	0.1	185	19.5	33.6
2	1200	5000	15	30	0.1	50	19	30.9
2	1200	5000	21	30	0.01	60	20.7	34.5
2	1320	5000	1	220	1.31	260	15.7	28.1
2	1320	5000	5	220	0.57	261	18	28.1
2	1320	5000	10	220	0.41	241	20.1	22
2	1320	5000	15	220	0.22	45	20.2	23.2

(Continued)

Appendix R. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
2	1320	5000	20	220	0.1	80	21.2	34.8
2	1400	5000	1	30	0.63	266	9.9	25.2
2	1400	5000	5	30	0.22	240	16.9	25.7
2	1400	5000	10	30	0.22	335	20	34.6
2	1400	500	15	30	0.3	45	20.2	37.9
2	1400	5000	22	30	0.1	335	20.8	28.4
5	810	2500	1	40	1.4	356	10	100.9
5	810	2500	5	40	1.1	46	17.5	40.7
5	810	2500	10	40	1.2	66	20	53.7
5	810	2500	15	40	1.1	16	20	102.5
5	810	2500	22	40	0.9	26	21	94
5	1115	4400	1	220	0.78	106	17.9	119
5	1115	4400	5	220	0.85	140	19.5	140.4
5	1115	4400	10	220	0.61	61	20	134.3
5	1115	4400	15	220	0.3	15	21	173.4
5	1115	4400	19	220	0.32	210	22	338.1

(Continued)

Appendix R. (Concluded)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
5	1530	4400	1	220	0.06	131	17	77.4
5	1530	4400	5	220	0.41	214	20	83.1
5	1530	4400	10	220	0.36	261	18	107.3
5	1530	4400	15	220	0.41	256	20.5	105.5
5	1530	4400	21	220	0.2	260	21.5	90.7
6	810	3750	1	30	0.72	104	13.2	22.6
6	810	3750	5	30	0.51	59	16.5	54
6	810	3750	10	30	0.5	44	15.6	31
6	810	3750	15	30	0.5	109	16	47
6	810	3750	21	30	0.5	109	15	43.2
6	1210	2000	1	30	0.9	20	19.5	48.9
6	1210	2000	5	30	1.2	45	18.9	41.9
6	1210	2000	10	30	0.81	40	19.3	53.4
6	1210	2000	15	30	0.92	340	19.4	50

Appendix S
Open-Bucket Clamshell Dredge Concentrations at Black Rock Harbor, 1983

Appendix S. Open Bucket Clamshell Dredge Concentrations at Black Rock Harbor, 1983

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
5	820	1600	1	50	1.2	186	10.1	60
5	820	1600	5	50	1.6	186	19	90.5
5	820	1600	10	50	1.2	151	20.4	89.3
5	820	1600	17	50	0.99	71	20.8	543.3
5	845	800	1	60	0.58	76	10.1	35
5	845	800	5	60	0.64	131	18	65.4
5	845	800	10	60	0.72	91	19	65
5	845	800	15	60	0.42	6	20	76
5	845	800	19	60	0.36	16	20.9	90
5	935	400	1	40	1.8	86	16	59.6
5	935	400	5	40	1.7	196	19.5	99.7
5	935	400	10	40	1.5	51	19.1	78.8
5	935	400	15	40	1.7	121	20	50.1
5	945	200	1	70	1.1	161	14	66.5
5	945	200	5	70	0.94	201	16.2	59

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
5	945	200	10	70	0.85	151	20	79
5	945	200	15	70	0.72	166	20.9	80.7
5	1000	100	1	30	0.72	50	14.9	12.3
5	1000	100	5	30	0.36	36	14.1	33
5	1000	100	10	30	0.67	86	20.4	39.2
5	1000	100	16	30	0.54	270	20.1	0
5	1010	100	1	230	0	0	18	14
5	1010	100	5	230	0	0	20	71
5	1010	100	10	230	0	0	20.9	105.9
5	1010	100	15	230	0	0	21	710.5
5	1020	100	1	230	0.64	111	19	134.5
5	1020	200	5	230	0.45	15	19.4	74
5	1020	200	10	230	0.71	31	20.2	38.2
5	1020	200	15	230	0.67	150	20	234.6
5	1020	200	20	230	0.58	321	20.9	2838

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
5	1035	400	1	220	0.58	81	19	131.1
5	1035	400	5	220	0.41	325	19.5	100.4
5	1035	400	10	220	0.71	96	20	218.7
5	1035	400	16	220	0.58	121	20.5	466.9
5	1045	800	1	220	0.78	261	15.5	112
5	1045	800	5	220	0.32	300	18	124.4
5	1045	800	10	220	0.45	270	20.9	119.4
5	1045	800	15	220	0.63	210	21	161.4
5	1045	800	19	220	0.5	151	21	147.8
5	1100	1600	1	220	0.54	66	16	125.2
5	1100	1600	5	220	0.3	50	19	153
5	1100	1600	10	220	0.22	47	21	230.6
5	1100	1600	18	220	0.5	301	21.2	176.8
5	1345	100	1	60	0	0	13	88.7
5	1345	100	5	60	0	0	16.1	269.5

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
5	1345	100	10	60	0	0	19	260.5
5	1345	100	15	60	0	0	20	139
5	1355	200	1	40	0.14	126	13.8	95.9
5	1355	200	5	40	0.32	251	18	308
5	1355	200	10	40	0.1	210	18	184
5	1400	200	15	40	0.1	90	20	83.1
5	1400	400	1	50	0.14	34	11.1	62.3
5	1400	400	5	50	0.6	310	17.9	69
5	1400	400	10	50	0.36	49	21	382
5	1410	400	13	50	0.14	329	21.5	104.2
5	1410	800	1	50	0.22	340	13.9	65.3
5	1410	800	5	50	0.14	179	17.5	69.7
5	1410	800	10	50	0.14	284	20	88.7
5	1410	800	15	50	0.3	195	20	11.2
5	1410	800	17	50	2.2	285	21	90.6

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
5	1425	1600	1	50	0.1	90	12	107.2
5	1425	1600	5	50	0.14	316	17	113.2
5	1425	1600	10	50	0.01	90	18.5	128.2
5	1425	1600	15	50	0.22	175	21	109.9
5	1435	800	1	60	0.2	145	13	134.3
5	1435	800	5	60	0.58	49	18	125.7
5	1435	800	10	60	0.2	355	20	111.6
5	1435	800	15	60	0.1	70	21	110.8
5	1435	800	18	60	0.28	129	21	123.4
5	1445	400	1	60	0.14	284	13	92
5	1445	400	5	60	0.32	40	17.1	92.2
5	1445	400	10	60	0.2	90	19.5	132.8
5	1445	400	15	60	0.16	16	17	125.8
5	1445	400	19	60	0.18	79	21.1	128.1
5	1455	200	1	60	0.3	75	12.5	99

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
5	1455	200	5	60	0.3	10	19	138.5
5	1455	200	10	60	0.22	75	19.4	349.4
5	1455	200	16	60	0.22	355	20.8	427.4
5	1505	100	1	60	0	0	13.8	76.4
5	1505	100	5	60	0	0	18	222
5	1505	100	10	60	0	0	21	703
5	1505	100	15	60	0	0	20	808.4
5	1510	100	1	150	0	0	15	84.5
5	1510	100	5	150	0	0	16.8	180.3
5	1510	100	10	150	0	0	20	194.7
5	1510	100	14	150	0	0	20	743.8
5	1520	200	1	140	0	0	16.8	90.4
5	1520	200	1	140	0	0	17	95.1
5	1520	200	10	40	0	0	20.9	122.7
5	1530	200	13	140	0	0	21	130.3

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
6	830	100	1	235	0.64	64	13	31.3
6	830	100	5	235	0.51	64	20	50.6
6	830	100	10	235	0.45	54	20.3	52
6	830	100	15	235	0.81	49	20.8	142.8
6	830	100	20	235	0.72	64	20	1320
6	840	200	1	240	0.71	134	14	126
6	840	200	5	240	0.89	184	15.8	294
6	840	200	10	240	0.8	184	19	3600
6	840	200	15	240	0.71	319	21.4	1620
6	850	400	1	240	0.5	154	15	82.1
6	850	400	5	245	0.42	159	16	195
6	850	400	10	245	0.42	164	20.1	609
6	850	400	15	245	0.63	265	20.5	491
6	900	800	1	245	0.32	61	16.2	27.1
6	900	800	5	245	0.32	15	20	43.1

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
6	900	800	10	245	0.32	20	21	60
6	900	800	15	245	0.61	30	21	86.5
6	900	800	20	245	0.61	30	21.3	569
6	950	1600	1	245	0.5	45	17.3	76.1
6	950	1600	5	235	0.36	359	20	38.1
6	950	1600	10	235	0.41	315	20.8	50.9
6	950	1600	15	235	0.51	60	21	41.3
6	950	1600	20	235	0.81	225	21	93.8
6	1005	800	1	245	0.42	209	17.3	11
6	1005	800	5	245	0.51	15	19.6	33.3
6	1005	800	10	245	0.45	20	20	38.9
6	1005	800	15	245	0.81	235	20.6	71.1
6	1015	400	1	245	0.91	360	15.9	46.6
6	1015	400	5	245	0.81	90	19	28.6
6	1015	400	10	245	0.8	25	21	53.3

(Continued)

Appendix S. (Continued)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
6	1015	400	15	245	0.9	355	21	76.4
6	1055	200	1	240	0.72	145	15	44.6
6	1055	200	5	240	1	130	18	35.4
6	1055	200	10	240	0.8	270	20	68.3
6	1055	200	15	240	0.21	224	20.9	493
6	1110	100	1	240	0	0	16	66.1
6	1110	100	5	240	0	0	19.5	28.1
6	1110	100	10	240	0	0	19.8	528
6	1110	100	15	240	0	0	20	816
6	1110	100	20	240	0	0	20	977
6	1120	200	1	250	0.22	69	15	85.6
6	1120	200	5	250	1	170	20	474
6	1120	200	10	250	0.8	245	19.1	772
6	1120	200	15	250	0.85	280	20.3	1200
6	1120	200	18	250	1.1	90	20	1984

(Continued)

Appendix S. (Concluded)

Date (May)	Time	Distance From Dredge (ft)	Sample Depth (ft)	Azimuth From Dredge (deg)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg/ℓ)
6	1135	400	1	245	0.9	190	13.2	186.9
6	1135	400	5	245	1.2	315	18.3	426
6	1135	400	10	245	1.2	290	20.3	850
6	1135	400	15	245	1.1	45	20.3	1406
6	1135	400	19	245	1.2	205	20	876
6	1145	800	1	255	1.1	260	14.5	62.9
6	1145	800	5	255	1.1	345	20	93.6
6	1145	800	10	255	1.2	90	20	531
6	1145	800	15	255	1.1	240	20.9	0
6	1155	1600	1	255	1.2	30	15.9	33.7
6	1155	1600	5	255	1.2	135	18	63.1
6	1155	1600	10	255	1.3	235	20	78.5
6	1155	1600	15	255	1	255	20.4	53.5

Appendix T
Background Concentrations at Duwamish Waterway, 1984

Appendix T. Background Concentrations at Duwamish Waterway, 1984

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment
26	838	2000	355	5	0.5	118	7	11
26	835	2000	355	10	0.3	80	14	19.3
26	832	2000	355	20	0.1	54	16	19.1
26	829	2000	355	30	0.1	330	16	26.1
26	825	2000	355	40	0.1	34	14	20

Appendix U
Open-Bucket Clamshell Dredge Concentrations at Duwamish Waterway, 1984

Appendix U. Open-Bucket Clamshell Dredge Concentrations at Duwamish Waterway, 1984

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	936	0	At dredge	5				8.2
26	940	0	At dredge	5				7.1
26	940	0	At dredge	5				8
26	920	0	At dredge	15				31.4
26	925	0	At dredge	15				38.4
26	925	0	At dredge	15				35
26	910	0	At dredge	30				21.5
26	912	0	At dredge	30				21
26	950	0	At dredge	30				12
26	955	0	At dredge	30				4.9
26	1025	0	At dredge	5				55
26	1020	0	At dredge	5				208
26	1010	0	At dredge	15				27
26	1005	0	At dredge	15				27.5

(Continued)

Appendix U. (Continued)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	1210	0	At dredge	5				6
26	1205	0	At dredge	5				6.9
26	1155	0	At dredge	15				63.5
26	1150	0	At dredge	15				77
26	1135	0	At dredge	30				21
26	1140	0	At dredge	30				14
26	1255	0	At dredge	5				7.3
26	1250	0	At dredge	5				5.7
26	1240	0	At dredge	15				88.2
26	1235	0	At dredge	15				80.8
26	1225	0	At dredge	30				41.1
26	1229	0	At dredge	30				52.4
26	1340	0	At dredge	5				101
26	1335	0	At dredge	5				104

(Continued)

Appendix U. (Continued)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	1325	0	At dredge	15				437
26	1320	0	At dredge	15				462
26	1310	0	At dredge	30				81.4
26	1305	0	At dredge	30				83
26	1425	0	At dredge	5				78.7
26	1420	0	At dredge	5				98.4
26	1410	0	At dredge	15				30.6
26	1405	0	At dredge	15				76
26	1355	0	At dredge	30				138
26	1350	0	At dredge	30				127
26	1435	0	At dredge	30				249
26	1440	0	At dredge	30				150
26	1445	0	At dredge	30				30.4
26	946	400	163	5	1.1	100	3	6

(Continued)

Appendix U. (Continued)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	943	400	163	15	0.2	142	16	2
26	942	400	163	30	0.5	334	16	3.4
26	940	400	163	40	0.1	110	16	18
26	1040	200	163	5	0.7	52		7.8
26	1037	200	163	15	0.4			25.2
26	1035	200	163	30	0.6			10
26	1030	200	163	40	0.3			8.3
26	1130	100	163	5				6
26	1131	100	163	15				5.2
26	1134	100	163	20				2.1
26	1136	100	163	25				54.2
26	1138	100	163	40				90.4
26	1200	200	200	5				12.1

(Continued)

Appendix U. (Continued)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	1203	200	200	15				5.6
26	1204	200	200	20				37.2
26	1205	200	200	40				103
26	1240	100	163	5	0.6	124	3	6.6
26	1235	100	163	15	0.3	170	9	18
26	1243	100	163	25	0.2	122		117
26	1230	100	163	35	0.1	190	16	157
26	1336	100	343	5	0.4	135	3	28.7
26	1330	100	343	15	0.2	73	16	198
26	1320	100	343	25	0.2	124	17	36
26	1357	200	343	5	0.4	232	3	32.2
26	1354	200	343	15	0.3	244	16	6.4
26	1355	200	343	25	0.3	248		20.6

(Continued)

Appendix U. (Continued)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	1350	200	343	34	0.1	70	16	11.1
26	1416	400	343	5	0.3	216	5	12.1
26	1414	400	343	15	0.4	174	16	6.2
26	1411	400	343	28	0.2	18	16	15.1
26	1436	800	343	5	0.5	174	4	6
26	1435	800	343	15	0.3	124	16	11
26	1434	800	343	26	0.2	262	9	11
26	950	450	190	5				5.2
26	952	450	190	15				5.6
26	954	450	190	20				2.8
26	1033	300	210	5				5.2

(Continued)

Appendix U. (Continued)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	1034	300	210	15				5.2
26	1036	300	210	15				3
26	1040	300	210	20				2.8
26	1041	300	210	24				132
26	1232	225	226	5				6
26	1234	225	226	15				1
26	1237	225	226	20				2.6
26	1312	100	255	5				4.8
26	1313	100	255	15				5.2
26	1314	100	255	20				2
26	1316	100	255	28				41.2
26	1326	150	280	5				4.8
26	1328	150	280	15				5.4

(Continued)

Appendix U. (Continued)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current		Salinity (ppt)	Total Suspended Sediment (mg)
					Speed (fps)	Azimuth (deg)		
26	1335	150	280	20				4
26	1337	150	280	39				149
26	1354	300	300	5				12
26	1356	300	300	15				6.8
26	1357	300	300	20				6.6
26	1358	300	300	40				7.8
26	1414	450	319	5				6.2
26	1415	450	319	15				8
26	1416	450	319	20				19
26	1417	450	319	38				22.8
26	1434	825	330	5				9
26	1435	825	330	15				11.1

(Continued)

Appendix U. (Concluded)

Date (March)	Time	Distance From Dredge (ft)	Azimuth From Dredge (deg)	Sample Depth (ft)	Current Speed (fps)	Current Azimuth (deg)	Salinity (ppt)	Total Suspended Sediment (mg)
26	1436	825	330	20				8.4
26	1437	825	330	40				9.4

Appendix V
Open-Bucket Clamshell Dredge Background and Dredging Concentrations at Lake City, 1984

Appendix V. Open Bucket Clamshell Dredge Background and Dredging Concentrations at Lake City, 1984

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.221	16	915	50	270	5	14	12
711.222	16	915	50	270	10	5	8
711.223	16	915	50	270	25	5	129
711.224	16	915	50	270	35	9	286
711.231	16	940	100	60	5	14	18
711.232	16	940	100	60	15	5	11
711.233	16	940	100	60	25	5	21
711.234	16	940	100	60	32	9	580
711.241	16	940	50	225	5	14	7
711.242	16	940	50	225	15	5	29
711.243	16	940	50	225	25	5	32
711.251	16	1010	100	105	5	14	29
711.252	16	1010	100	105	15	5	42
711.253	16	1010	100	105	25	5	27

(Continued)

Appendix V. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.261	16	1036	200	105	5	14	10
711.262	16	1036	200	105	15	5	44
711.263	16	1036	200	105	25	5	61
711.274	16	1036	200	105	35	9	20
711.271	16	1100	400	105	5	14	5
711.272	16	1100	400	105	15	5	7
711.273	16	1100	400	105	25	5	8
711.274	16	1100	400	105	34	9	9
711.281	16	1114	800	105	5	14	12
711.282	16	1114	800	105	15	5	10
711.283	16	1114	800	105	25	5	9
711.284	16	1114	800	105	34	9	13
711.291	16	1127	1600	105	5	14	16
711.292	16	1127	1600	105	15	5	11
711.293	16	1127	1600	105	25	5	3
711.294	16	1127	1600	105	34	9	16

(Continued)

Appendix V. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.301	16	1310	200	225	5	14	20
711.302	16	1310	200	225	15	5	23
711.303	16	1310	200	225	23	9	21
711.311	16	1320	400	225	5	24	5
711.312	16	1320	400	225	15	5	11
711.313	16	1320	400	225	20	9	4
711.321	16	1330	100	225	5	14	22
711.322	16	1330	100	225	15	5	54
711.323	16	1330	100	225	21	9	50
711.331	16	1340	100	270	5	14	9
711.332	16	1340	100	270	15	5	11
711.333	16	1340	100	270	21	9	44
711.341	16	1350	200	270	5	14	30
711.342	16	1350	200	270	15	5	34
711.343	16	1350	200	270	30	9	133

(Continued)

Appendix V. (Concluded)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.351	16	1400	400	270	5	14	5
711.352	16	1400	400	270	10	5	8
711.353	16	1400	400	270	20	9	7
711.361	16	1410	50	270	5	14	11
711.362	16	1410	50	270	15	5	27
711.363	16	1410	50	270	25	5	46
711.364	16	1410	50	270	35	9	274
711.371	16	1420	50	60	5	14	10
711.372	16	1420	50	60	15	5	22
711.373	16	1420	50	60	25	5	62
711.374	16	1420	50	60	35	9	258
711.381	16	1445	200	60	5	14	79
711.382	16	1445	200	60	15	5	101
711.383	16	1445	200	60	25	5	55
711.384	16	1445	200	60	35	9	139

Notes: Background Suspended Sediment is based on concentrations measured during non dredging periods. Total Suspended Sediment is total concentration during times of dredging.

Appendix W
Closed-Bucket Clamshell Dredge Background and Dredging Concentrations at Lake City, 1984

Appendix W. Closed Bucket Clamshell Dredge Background and Dredging Concentrations at Lake City, 1984

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.011	13	955	50	225	5	5	17
711.012	13	955	50	225	15	12	27
711.013	13	955	50	225	25	6	20
711.021	13	1000	50	60	5	5	32
711.022	13	1000	50	60	15	12	18
711.023	13	1000	50	60	25	6	51
711.024	13	1000	50	60	31	11	488
713.011	11	1025	200	225	5	5	13
713.012	11	1025	200	225	15	9	19
713.013	11	1025	200	225	25	10	18
713.021	11	1035	100	225	5	5	34
713.022	11	1035	100	225	15	9	22
713.023	11	1035	100	225	25	2	65
713.024	11	1035	100	225	35	10	257
713.231	12	1035	50	270	5	5	20
713.232	12	1035	50	270	10	7	25
713.233	12	1035	50	270	15	10	40

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.031	11	1040	400	225	5	5	6
713.032	11	1040	400	225	10	10	9
713.033	11	1040	400	225	20	9	14
713.241	12	1046	100	270	5	5	41
713.242	12	1046	100	270	15	10	41
713.243	12	1046	100	270	24	27	201
713.041	11	1050	100	270	5	5	29
713.042	11	1050	100	270	10	9	22
713.043	11	1050	100	270	22	10	24
713.251	12	1058	200	270	5	5	38
713.252	12	1058	200	270	15	10	28
713.253	12	1058	200	270	23	27	31
713.051	11	1108	200	270	5	5	13
713.052	11	1108	200	270	10	10	12
713.053	11	1108	200	270	22	9	58

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.061	11	1115	100	270	5	5	63
713.062	11	1115	100	270	9	10	54
713.063	11	1115	100	270	14	9	65
713.261	12	1119	50	105	5	5	13
713.262	12	1119	50	105	15	10	17
713.263	12	1119	50	105	25	27	137
713.264	12	1119	50	105	38	27	500
713.071	11	1120	100	270	1	5	48
713.072	11	1120	100	270	5	5	64
713.073	11	1120	100	270	9	10	66
713.074	11	1120	100	270	14	9	63
713.081	11	1130	50	60	5	5	39
713.082	11	1130	50	60	15	10	33
713.083	11	1130	50	60	25	9	108
713.084	11	1130	50	60	33	10	339
713.091	11	1142	100	105	5	5	28
713.092	11	1142	100	105	15	10	29
713.093	11	1142	100	105	29	9	66

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.271	12	1147	50	225	5	5	15
713.272	12	1147	50	225	15	10	11
713.273	12	1147	50	225	25	27	29
713.101	11	1156	200	105	5	2	5
713.102	11	1156	200	105	15	3	6
713.103	11	1156	200	105	25	2	29
713.281	12	1157	200	225	38	27	139
711.031	13	1250	100	270	5	5	22
711.032	13	1250	100	270	15	12	27
711.033	13	1250	100	270	25	6	47
711.034	13	1250	100	270	35	11	117
711.041	13	1300	400	270	5	10	10
711.042	13	1300	400	270	15	6	13
711.043	13	1300	400	270	21	11	26
711.051	13	1307	200	270	5	10	19
711.052	13	1307	200	270	15	6	12
711.053	13	1307	200	270	28	11	48

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.061	13	1316	100	225	5	10	36
711.062	13	1316	100	225	15	6	34
711.063	13	1316	100	225	25	6	91
711.064	13	1316	100	225	38	11	370
711.071	13	1322	200	225	5	10	11
711.072	13	1322	200	225	10	6	8
711.073	13	1322	200	225	15	11	14
711.081	13	1325	400	225	5	10	7
711.082	13	1325	400	225	15	12	20
711.083	13	1325	400	225	23	11	43
713.291	12	1330	100	105	5	5	75
713.292	12	1330	100	105	30	27	73
713.111	11	1331	400	105	5	2	1
713.112	11	1331	400	105	15	3	4
713.113	11	1331	400	105	25	2	10
713.114	11	1331	400	105	34	10	5

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.091	13	1340	50	225	5	10	23
711.092	13	1340	50	225	15	12	40
711.093	13	1340	50	225	25	6	163
711.094	13	1340	50	225	36	11	950
713.121	11	1341	800	105	5	2	11
713.122	11	1341	800	105	15	3	5
713.123	11	1341	800	105	25	2	16
713.124	11	1341	800	105	35	10	15
713.301	12	1346	200	105	5	5	28
713.302	12	1346	200	105	15	10	54
713.303	12	1346	200	105	18	28	111
711.101	13	1350	50	60	5	5	6
711.102	13	1350	50	60	15	12	23
711.103	13	1350	50	60	25	6	150
711.104	13	1350	50	60	35	11	600

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.131	11	1356	1600	105	5	2	11
713.132	11	1356	1600	105	15	3	5
713.133	11	1356	1600	105	25	2	2
713.134	11	1356	1600	105	35	10	13
711.111	13	1357	100	105	5	5	83
711.112	13	1357	100	105	15	12	57
711.113	13	1357	100	105	30	11	248
713.311	12	1405	400	105	5	5	17
713.312	12	1405	400	105	15	10	11
713.313	12	1405	400	105	25	27	10
713.314	12	1405	400	105	38	27	14
711.121	13	1405	200	105	5	5	9
711.122	13	1405	200	105	15	12	14
711.123	13	1405	200	105	25	6	13
711.124	13	1405	200	105	36	11	6

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.141	11	1408	1600	60	5	2	20
713.142	11	1408	1600	60	15	3	9
713.143	11	1408	1600	60	25	2	8
713.144	11	1408	1600	60	36	10	5
711.131	13	1410	400	105	5	5	9
711.132	13	1410	400	105	15	12	6
711.133	13	1410	400	105	25	6	9
711.134	13	1410	400	105	33	11	1
713.151	11	1419	800	60	5	2	6
713.152	11	1419	800	60	15	3	7
713.153	11	1419	800	60	25	2	3
713.154	11	1419	800	60	36	10	5
711.141	13	1420	800	105	5	5	13
711.142	13	1420	800	105	15	12	13
711.143	13	1420	800	105	25	6	10
711.144	13	1420	800	105	32	11	8

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.161	11	1423	400	60	5	2	5
713.162	11	1423	400	60	15	3	12
713.163	11	1423	400	60	25	2	21
713.164	11	1423	400	60	36	10	36
713.321	12	1430	800	105	5	5	6
713.322	12	1430	800	105	15	10	8
713.323	12	1430	800	105	25	27	9
713.324	12	1430	800	105	35	27	30
713.171	11	1432	200	60	5	2	4
713.172	11	1432	200	60	15	2	11
713.173	11	1432	200	60	31	10	97
711.151	13	1435	1600	105	5	6	6
711.152	13	1435	1600	105	15	12	17
711.153	13	1435	1600	105	25	6	9
711.154	13	1435	1600	105	35	11	31

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.181	11	1440	50	60	5	2	44
713.182	11	1440	50	60	15	3	54
713.183	11	1440	50	60	25	2	236
713.184	11	1440	50	60	38	10	449
711.161	13	1445	1600	60	5	5	4
711.162	13	1445	1600	60	15	12	20
711.163	13	1445	1600	60	25	6	7
711.164	13	1445	1600	60	38	11	25
713.191	11	1452	0	105	5	2	7
713.192	11	1452	0	105	10	3	5
713.193	11	1452	0	105	15	2	19
711.171	13	1452	800	60	5	5	18
711.172	13	1452	800	60	15	12	15
711.173	13	1452	800	60	25	6	7
711.174	13	1452	800	60	38	11	63

(Continued)

Appendix W. (Continued)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
711.181	13	1500	400	60	5	5	12
711.182	13	1500	400	60	15	12	13
711.183	13	1500	400	60	25	6	11
711.184	13	1500	400	60	35	11	94
713.201	11	1505	100	225	5	5	83
713.202	11	1505	100	225	10	10	73
713.203	11	1505	100	225	15	10	98
713.204	11	1505	100	225	24	9	115
711.191	13	1507	0	60	5	5	73
711.192	13	1507	0	60	15	12	61
711.193	13	1507	0	60	30	6	90
711.201	13	1512	0	60	35	11	240
711.211	13	1514	0	60	35	11	3800
713.211	11	1510	200	225	5	5	48
713.212	11	1510	200	225	10	10	39
713.213	11	1510	200	225	16	9	59

(Continued)

Appendix W. (Concluded)

Sample Number	Date (April)	Time	Distance From Dredge (ft)	Azimuth From Depth (deg)	Sample Depth (ft)	Background Suspended Sediment (mg/ℓ)	Total Suspended Sediment (mg/ℓ)
713.221	11	1515	400	225	5	5	20
713.222	11	1515	400	225	15	10	10
713.223	11	1515	400	225	22	9	33
713.331	12	1540	100	225	5	5	20
713.332	12	1540	100	225	15	10	48
713.333	12	1540	100	225	20	27	83
713.341	12	1550	400	225	5	5	21
713.342	12	1550	400	225	15	10	37
713.343	12	1550	400	225	21	27	47
713.351	12	1554	200	225	5	5	33
713.352	12	1554	200	225	15	10	5
713.353	12	1554	200	225	20	27	116

Notes: Background Suspended Sediment is based on concentrations measured during non dredging periods. Total Suspended Sediment is total concentration during times of dredging.

Appendix X
Background Concentrations at Calumet River, 1985

Appendix X. Background Concentrations at Calumet River, 1985

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
1B	20	1717	27	18	300	50
1B	20	1718	15	12	300	50
1B	20	1719	5	11	300	50
2B	20	1722	27	11	150	325
2B	20	1723	15	12	150	325
2B	20	1724	5	10	150	325
3B	20	1731	27	12	-300	-75
3B	20	1732	15	10	-300	-75
3B	20	1733	5	10	-300	-75
4B	20	1736	27	10	-400	150
4B	20	1739	15	12	-400	150
4B	20	1740	5	10	-400	150
5B	20	1742	27	13	-825	-200
5B	20	1744	15	12	-825	-200
5B	20	1745	5	18	-825	-200

(Continued)

Appendix X. (Continued)

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
3	23	1226	27	285	50	0
3	23	1227	15	51	50	0
3	23	1228	15	45	50	0
3	23	1229	5	52	50	0
4	23	1232	27	45	200	0
4	23	1234	15	34	200	0
4	23	1235	5	45	200	0
5	23	1237	27	22	400	0
5	23	1238	15	23	400	0
5	23	1239	5	34	400	0
6	23	1242	27	14	600	0
6	23	1243	15	12	600	0
6	23	1244	5	18	600	0
6	23	1245	5	15	600	0
3	23	852	27	98	50	0
3	23	857	27	130	50	0
3	23	901	27	76	50	0
3	23	906	15	33	50	0

(Continued)

Appendix X. (Concluded)

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
6B	20	1746	27	11	-900	0.01
6B	20	1747	15	11	-900	0.01
6B	20	1749	5	10	-900	0.01
7B	20	1752	27	10	650	350
7B	20	1754	15	10	650	350
7B	20	1755	5	9	650	350

Appendix Y
Open-Bucket Clamshell Dredge Concentrations at Calumet River, 1985

Appendix Y. Open Bucket Clamshell Dredge Concentrations at Calumet River, 1985

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
4	22	1055	27	54	200	0
4	22	1103	27	56	200	0
4	22	1110	27	56	200	0
4	22	1117	15	36	200	0
4	22	1122	15	38	200	0
4	22	1128	15	50	200	0
4	22	1136	5	22	200	0
5	22	1201	27	57	400	0
5	22	1203	15	21	400	0
5	22	1204	5	20	400	0
3	22	1519	27	85	50	0
3	22	1531	15	122	50	0
3	22	1544	5	33	50	0
11	22	1500	27	24	200	100
11	22	1502	15	16	200	100
11	22	1504	5	18	200	100

(Continued)

Appendix Y. (Continued)

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
12	22	1515	27	14	200	200
12	22	1518	15	14	200	200
12	22	1519	5	14	200	200
13	22	1528	27	16	200	300
13	22	1530	25	16	200	300
13	22	1531	5	14	200	300
7	22	1544	27	15	800	0
7	22	1546	27	15	800	0
7	22	1547	15	14	800	0
7	22	1549	5	14	800	0
2	23	945	27	140	-50	0
2	23	946	15	20	-50	0
2	23	947	5	12	-50	0
1	23	957	27	37	-150	0
1	23	958	15	18	-150	0
1	23	959	5	11	-150	0

(Continued)

Appendix Y. (Continued)

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
8	23	1002	27	79	0	-50
8	23	1004	15	26	0	-50
8	23	1005	15	25	0	-50
8	23	1006	5	13	0	-50
9	23	1009	27	540	0	50
9	23	1010	15	33	0	50
9	23	1011	5	13	0	50
10	23	1019	27	20	0	100
10	23	1021	15	16	0	100
10	23	1022	5	11	0	100
12	23	1026	27	14	200	200
12	23	1028	15	14	200	200
12	23	1029	5	12	200	200
12	23	1030	5	13	200	200
6	23	1037	27	14	600	0
6	23	1038	15	14	600	0
6	23	1039	5	13	600	0

(Continued)

Appendix Y. (Continued)

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge Axial Distance (ft)	Position Relative to Dredge Lateral Distance (ft)
2	23	1136	27	49	50	0
2	23	1137	15	30	50	0
2	23	1138	5	14	50	0
8	23	1140	27	210	0	-50
8	23	1141	15	56	0	-50
8	23	1143	5	10	0	-50
1	23	1145	27	49	-150	0
1	23	1146	27	52	-150	0
1	23	1147	15	37	-150	0
1	23	1148	5	15	-150	0
9	23	1203	27	62	0	50
9	23	1204	15	38	0	50
9	23	1205	5	40	0	50
10	23	1206	27	49	0	100
10	23	1207	15	29	0	100
10	23	1209	5	20	0	100

(Continued)

Appendix Y. (Continued)

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
3	23	911	15	56	50	0
3	23	934	15	36	50	0
3	23	938	5	58	50	0
3	23	941	5	68	50	0
3	23	944	5	70	50	0
4	23	1000	27	31	200	0
4	23	1005	27	29	200	0
4	23	1012	27	30	200	0
4	23	1018	15	30	200	0
4	23	1040	15	15	200	0
4	23	1046	15	14	200	0
4	23	1053	5	14	200	0
4	23	1058	5	15	200	0
4	23	1103	5	14	200	0
4	23	1114	5	17	200	0
2	23	1139	27	130	-50	0
2	23	1147	27	140	-50	0
2	23	1156	27	69	-50	0
2	23	1203	15	50	-50	0
2	23	1225	15	55	-50	0

(Continued)

Appendix Y. (Concluded)

Station Number	Date (August)	Time	Sample Depth (ft)	Total Suspended Sediment (mg/ℓ)	Position Relative to Dredge: Axial Distance (ft)	Position Relative to Dredge: Lateral Distance (ft)
2	23	1230	15	53	-50	0
2	23	1232	5	10	-50	0
2	23	1237	5	9	-50	0
2	23	1243	5	44	-50	0

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13. ABSTRACT *(Maximum 200 words)*

Dredging in riverine, lacustrine, and estuarine environments introduces bottom sediments into overlying waters because of imperfect entrainment and incomplete capture of sediments resuspended during the dredging process and the spillage or leakage of sediments during subsequent transportation and disposal of the dredged sediments. Resuspension of bottom sediments and resulting dispersal may pose water quality problems in waters near dredging operations. Interest in this issue increases when the sediment being dredged is highly contaminated. Resuspension of sediments by dredging is affected by dredge characteristics, dredge operating conditions, properties of bottom and suspended sediments, and site–specific conditions such as bottom topography, ambient current, and depth. This report summarizes field studies conducted by the U.S. Army Corps of Engineers to assess the suspended sediment concentrations in the water column in the vicinity of various dredge types. These concentration data are combined with conceptual models for resuspended sediment source strength geometries and velocity patterns to estimate sediment source strengths for cutterhead and clamshell dredges. Although unverified, these models provide a starting point for a more thorough analytical evaluation of the entire resuspension, transport, and deposition process.

14. SUBJECT TERMS

Clamshell	Models	Source strength	Water quality
Cutterhead	Sediment	Suspended sediment	
Dredging	Sediment resuspension	Suspended solids	

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